USS

STAINLESS AND HEAT RESISTING STEELS

US STEEL

USS

Chromium and Chromium-Nickel Alloy Steels

USS 18-8

USS 18-8s

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USS Stabilized 18-8

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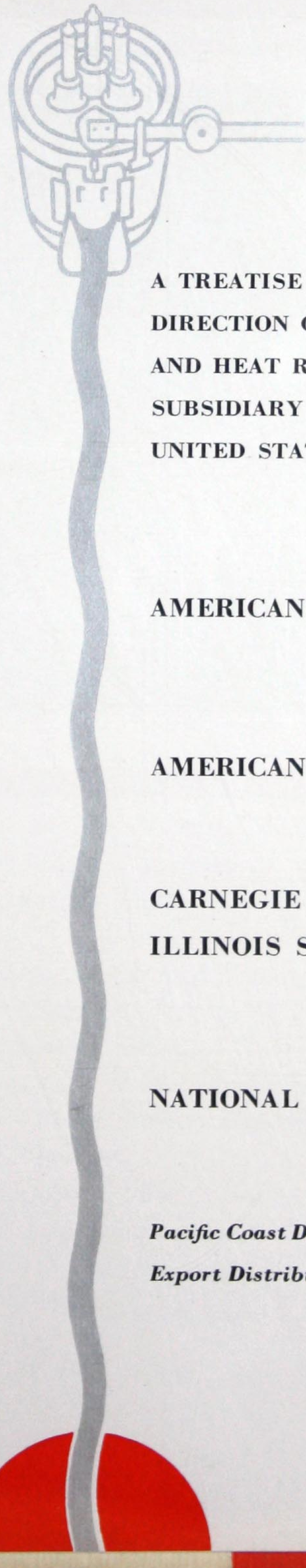
STAINLESS
AND HEAT RESISTING
ALLOY STEELS



A TREATISE PREPARED UNDER THE
DIRECTION OF THE COMMITTEE ON STAINLESS
AND HEAT RESISTING STEELS
SUBSIDIARY MANUFACTURING COMPANIES OF THE
UNITED STATES STEEL CORPORATION

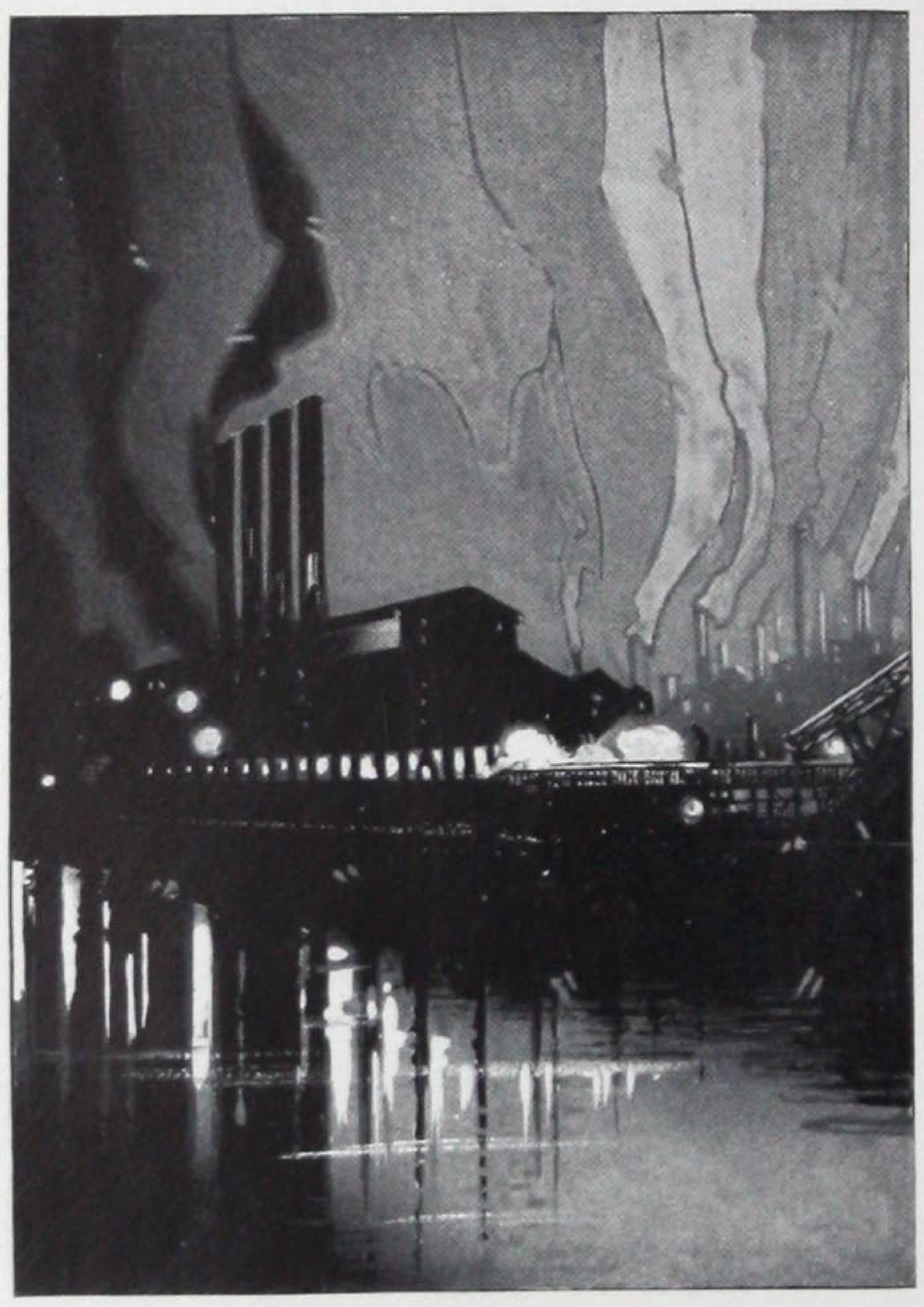
AMERICAN SHEET AND TIN PLATE COMPANY, Pittsburgh
Sheets and Light Plates

AMERICAN STEEL & WIRE COMPANY, Chicago
Cold Rolled Strip, Wire, and Wire Products

CARNEGIE STEEL COMPANY, Pittsburgh, *and*
ILLINOIS STEEL COMPANY, Chicago
Bars, Plates, Special Sections, and Semi-Finished Products

NATIONAL TUBE COMPANY, Pittsburgh
Pipe and Tubular Products

Pacific Coast Distributors: Columbia Steel Company, San Francisco
Export Distributors: U. S. Steel Products Company, New York City



FOREWORD

The Subsidiary Manufacturing Companies of the United States Steel Corporation produce a comprehensive series of Stainless and Heat Resisting Steels, which are available in finished and semi-finished products. These alloys are all of the relatively low carbon type, as distinct from the stainless cutlery grades, and may be broadly classified under the following two main headings:

(a) Chromium Alloy Steels (Magnetic)

(b) Chromium-Nickel Alloy Steels (Non-magnetic)

In each of these classes there are obtainable a number of types and grades, differing in chemical composition, so that a selection may be made to meet the requirements in various specific applications.

All of the Stainless and Heat Resisting Steels are electric furnace products, made under carefully controlled conditions. The Illinois Steel Company, having unusual facilities and complete equipment for this purpose, produces the semi-finished alloy steels for the other Subsidiary Companies of the United States Steel Corporation, as well as for its own requirements in the rolling of plates, bars, rounds, and miscellaneous shapes. The finished products are provided by the following Companies:

American Sheet and Tin Plate Company, Pittsburgh—*Sheets and Light Plates*

American Steel & Wire Company, Chicago—*Cold Rolled Strip, Wire, and Wire Products*

Carnegie Steel Company, Pittsburgh, and Illinois Steel Company, Chicago—*Bars, Plates, Special Sections, and Semi-Finished Products*

National Tube Company, Pittsburgh—*Pipe and Tubular Products*

The U S S Chromium-Nickel Alloy Steels are produced under the licenses of the Chemical Foundation, Inc., New York, and Fried. Krupp A. G. of Germany

The gleaming silvery lustre of U S S Stainless Tubing enriches the stairway and balcony railing in the Music Hall of Rockefeller Center, New York City

Stainless and Heat Resisting Steels

No one metal or alloy, equally adaptable to all purposes, has ever been produced by the science and art of metallurgy. But, in the pursuit of permanence as an ideal, the development of the alloys of chromium and iron, with or without nickel, has made available for industrial purposes a class of materials combining unusual resistance to corrosion with very desirable physical properties.

Chromium is the only alloying element which has been found to produce in iron alloys a condition approaching complete resistance to atmospheric corrosion. Chemical and metallurgical tests indicate that more than 11% chromium is necessary to provide this characteristic even in pure iron. The presence of carbon in the commercial alloy necessitates an additional amount of chromium because, under certain conditions, each unit of carbon may combine with as much as eighteen units of chromium and render that portion of the alloying element ineffectual in its protective function. The remainder of the chromium forms a homogeneous solid solution with the iron, and imparts to the alloy its notable resistance to corrosion. For practical purposes, something more than the minimum amount of chromium is added to provide a judicious margin of safety. Beyond this point, various grades of the alloy are produced to meet the requirements of particular conditions but, in all instances, the composition must likewise be regulated with due consideration to the physical properties of the resultant metal.

It may be of interest to turn to the scientist and inquire into his conception of the reason for the particular behavior of the chromium-iron alloys. Chromium itself is not a noble metal, such as gold and platinum. Its protective action, when combined with iron or low carbon steel, apparently is due to the formation of a characteristic surface film on the clean metal, always involving the presence of oxygen in some manner, and this film is conceived as being continuous, stable, so thin as to be invisible, yet an effective barrier against the further action of corrosive agents. An important condition, as mentioned in the foregoing statement, is that there must be oxygen available in the surroundings for the formation of the protective film. At elevated temperatures this film is equally important. It becomes thicker, loses transparency, and eventually forms a definite scale that is continuous and firmly adherent, and serves to protect the underlying metal against further oxidation. It is to the formation of this characteristic scale that the unique and important oxidation resisting qualities of the high chromium alloys are due—properties that confer distinct advantages upon these alloys in high temperature service.

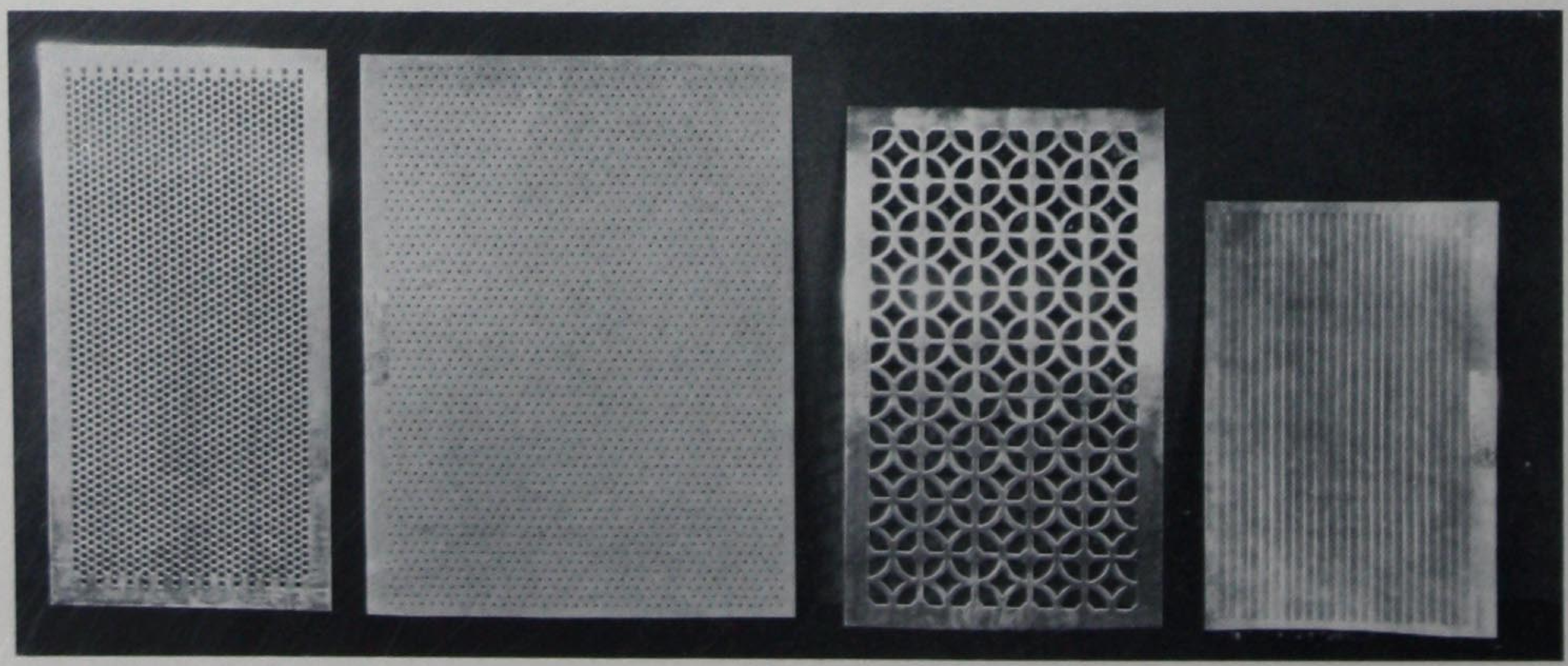
In the terminology of the metallographist, the chromium irons or low carbon chromium steels normally exist in the form of ferrite, the characteristic structure of iron below the lower critical point, and as such, may be attracted by a magnet.

In comparison with the high carbon stainless cutlery steels, the alloys of this class are less susceptible to hardening by heat treatment.

The addition of substantial proportions of nickel to the chromium-iron system provides a series of alloys with somewhat more pronounced resistance to many kinds of corrosive attack, and at the same time introduces important advantages with respect to the physical or mechanical properties of the metal. All of these benefits might be expected from a consideration of the characteristics of nickel itself.

In the first place, in many media nickel is less readily corrodible than iron, and it has the property of developing surface passivity in a manner similar to that of chromium, although not to the same extent. Altogether, the combination of iron, nickel, and chromium, in suitable proportions, produces an alloy of extraordinary usefulness which well merits the designation "stainless." Furthermore, in the matter of metallographic structure, which has an important bearing upon the physical properties, the addition of nickel has a marked influence upon the chromium-iron alloys. Whereas chromium and iron form solid solutions which are normally in the alpha (or ferritic) condition, the introduction of nickel to the extent of approximately 8% causes the alloys to assume and retain the gamma (or austenitic) state, provided they are properly processed and heat treated. The structure of the low carbon chromium-nickel steels (or irons) affects both their mechanical properties and their resistance to corrosion; hence this feature has been accorded the most painstaking study on the part of physical metallurgists and technologists.

These austenitic alloys are non-magnetic, and are not hardenable by heat treatment. They have a high degree of ductility, as properly annealed, and are particularly well adapted to deep drawing operations. Another interesting property of the austenitic alloys is their rapid increase in strength and hardness on cold working. Advantage has been taken of this characteristic for the produc-



U S S Stainless Sheets perforated for ornamental and other purposes

tion of cold rolled strip, wire, and tubes of very high tensile strength. These have been fabricated into airplane parts, rail cars, structural members, etc., with great success. The unique three-fold combination of high strength, light section, and maximum corrosion resistance available in this material will demand consideration for it in many new and important applications as these develop.

While the characteristics of the various grades of straight chromium and chromium-nickel low carbon steels will be discussed in detail later in the text, the following general and miscellaneous observations may be of interest at this point:

1. All of the alloys have higher tensile strengths than have ordinary steels of the same carbon content. In some cases, modification of the fabricating and forming procedures employed with other materials may be necessary in order to accommodate the processes to the distinctive properties of the various alloys.

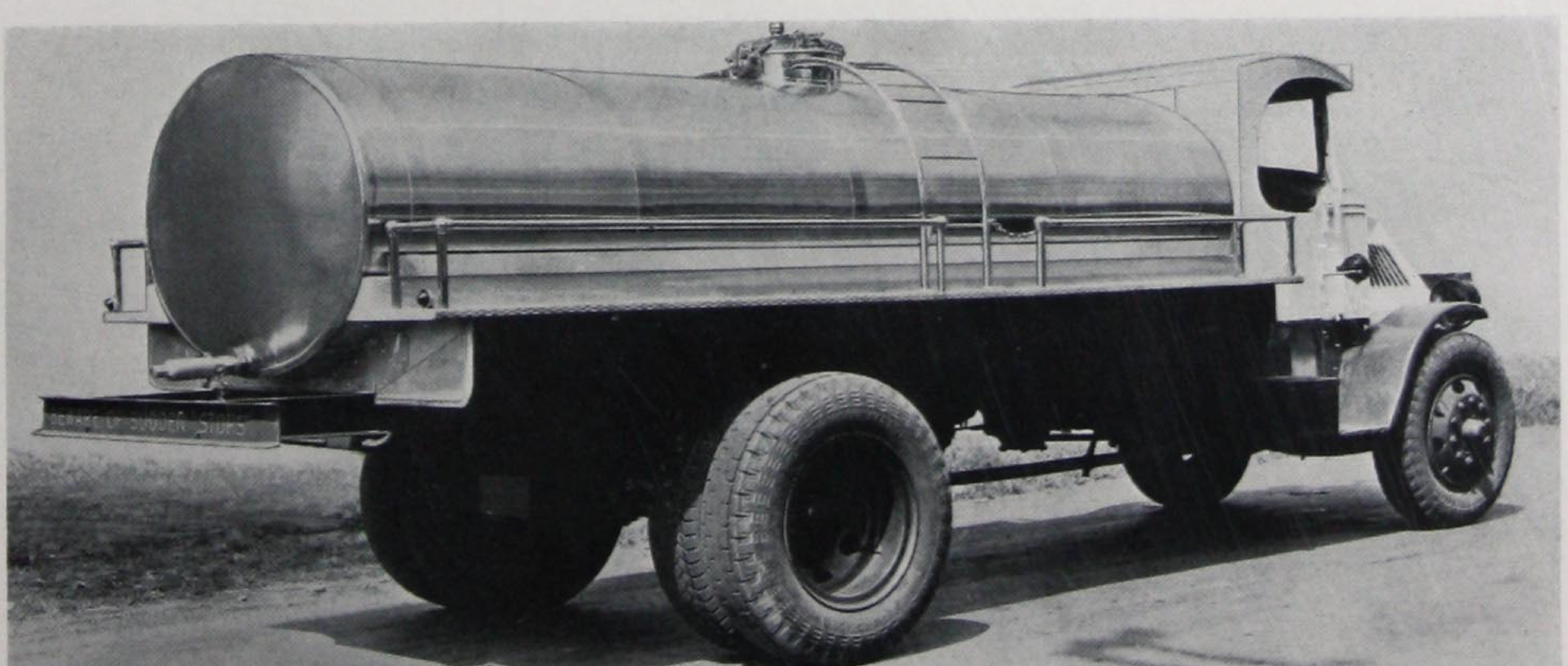
2. None of these alloys, with the exception of U S S 12, may be hardened appreciably by heat treatment, but in common with all metals they are hardened by cold work.

3. Since the alloys are highly resistant to corrosive attack, special solutions must be used in all pickling operations.

4. For those applications in which the highest degree of resistance to rusting or staining is desired, well cleaned surfaces are of primary importance.

5. The heat conductivity of all of these alloys is considerably lower than that of ordinary steel. Due allowance must be made for this feature, particularly in the heating of relatively heavy sections for forging or other hot working.

6. Unusual resistance to oxidation at high temperatures is a characteristic of both the straight chromium and the chromium-nickel low carbon steels. However, in some grades this property is more pronounced than in others, and a selection should be made on the basis of the conditions to be encountered. In general, the higher the chromium content, the better the resistance to oxidation at high temperatures.



Milk is given the utmost protection when Stainless Steel is used in transportation equipment

U S S Stainless Steel, used with other materials, greatly enhances the beauty of these plaques designed for Rockefeller Center. A typical example of ornamental values made permanent

U S S 18-8

This grade of the series of stainless steels manufactured by the Subsidiary Companies of the United States Steel Corporation has the widest applicability due to the combination of its unusual physical properties with a most thorough resistance to corrosive attack. U S S 18-8 is the result of developments in the field of the earlier "18 & 8" chromium-nickel alloys. It is a circumstance of far-reaching significance that a metal carrying the high proportion of special elements necessary to secure ample corrosion and high temperature resistance should, at the same time, through proper composition and controlled furnacing and fabrication, develop the amazing workability of U S S 18-8.

Composition

In order to provide metal of the greatest suitability for specific purposes, it has been found advisable to manufacture this type of steel over a moderate range of composition, as follows:

Chromium	17 to 20%	Silicon	Max. 0.75%
Nickel	8 to 12%	Carbon	Max. 0.15%
Manganese	Max. 0.50%		

Physical Properties

Before discussing the details of the recommended practice in the utilization of U S S 18-8, it is perhaps advisable to call attention to the usual physical properties developed in this alloy. These properties will vary somewhat with the composition and previous history of fabrication, but the values given in the table on page 46 are representative of the more important characteristics.

The table will likewise indicate that U S S 18-8 is amenable to almost every mode of working known to the metal workers' art. It may, of course, be forged, pierced, rolled (hot or cold), drawn into finest wire, spun, deep drawn, machined, welded, and finally exquisitely polished to a mirror surface which remains permanent and untarnishable even in moist air. As will be given in detail in the succeeding paragraph, the metal, in any form, completely resists the action of a great variety of chemicals, and even some strong acids, and is only mildly affected in the presence of ordinary atmospheres at considerably elevated temperatures—up to 1600 to 1650°F. In U S S 18-8, engineers and craftsmen find a material from which they may fabricate articles of enduring beauty and utility.

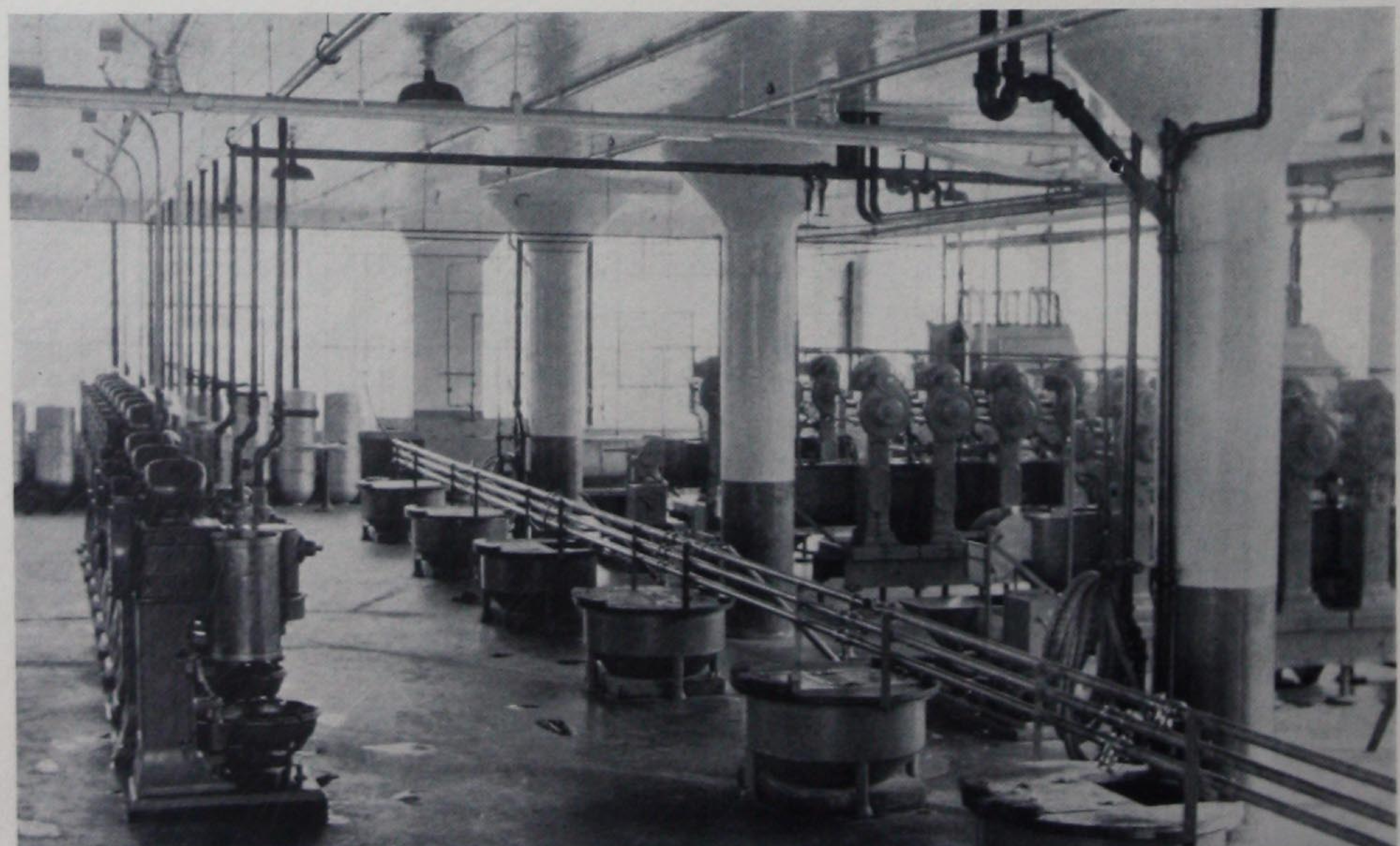
Resistance to Corrosion

There has been no single metal found in nature, not even excepting gold and platinum, which is unaffected by corrosive attack in all environments, and no

alloy has been developed which remains unattacked in all solutions. Moreover, it is true that, in general, only the rarer metals offer any considerable resistance to corrosive attack. The chromium-iron alloys are clearly the cheapest alloys which offer ample resistance to attack under some of the commonest and most active conditions. In addition to contributing desirable physical properties to U S S 18-8, the presence of nickel also extends the alloy's field of utility from the standpoint of inertness in the presence of corrosive substances.

The industrial reagents which are incapable of attacking clean surfaces of U S S 18-8 would make up a very long list, and no attempt will be made here to tabulate all of them. However, an impression of the kind of environment in which U S S 18-8 is highly corrosion resistant may be formed from the following examples:

Acetic Acid, cold, at any concentration
Acetic Acid, hot, up to 10%, approximately
Alkaline Solutions in general, including Ammonium Hydroxide
Bichloride of Mercury, dilute (usual antiseptic strength)
Carbolic Acid
Carbonated Water
Citric Acid, cold, moderate strength
Copper Sulphate
Fruit and Vegetable Juices
Hydrogen Peroxide
Hydrogen Sulphide
Laundry Solutions, with few exceptions
Milk and Dairy products
Nitric Acid
Photographic Solutions
Salt Solution
Sea Water
Sulphuric Acid, cold, very slight action
Sulphurous Acid
Wood Pulp
Yeast
Zinc Chloride, cold
Zinc Sulphate



U S S Stainless Steel Tubing used as conveyor lines for mayonnaise in mixing room of a nationally known food concern

It is convenient to consider the resistance of U S S 18-8 to surface attack as of *three types*—all dependent, however, upon the same inert surface condition characteristic of the metal.

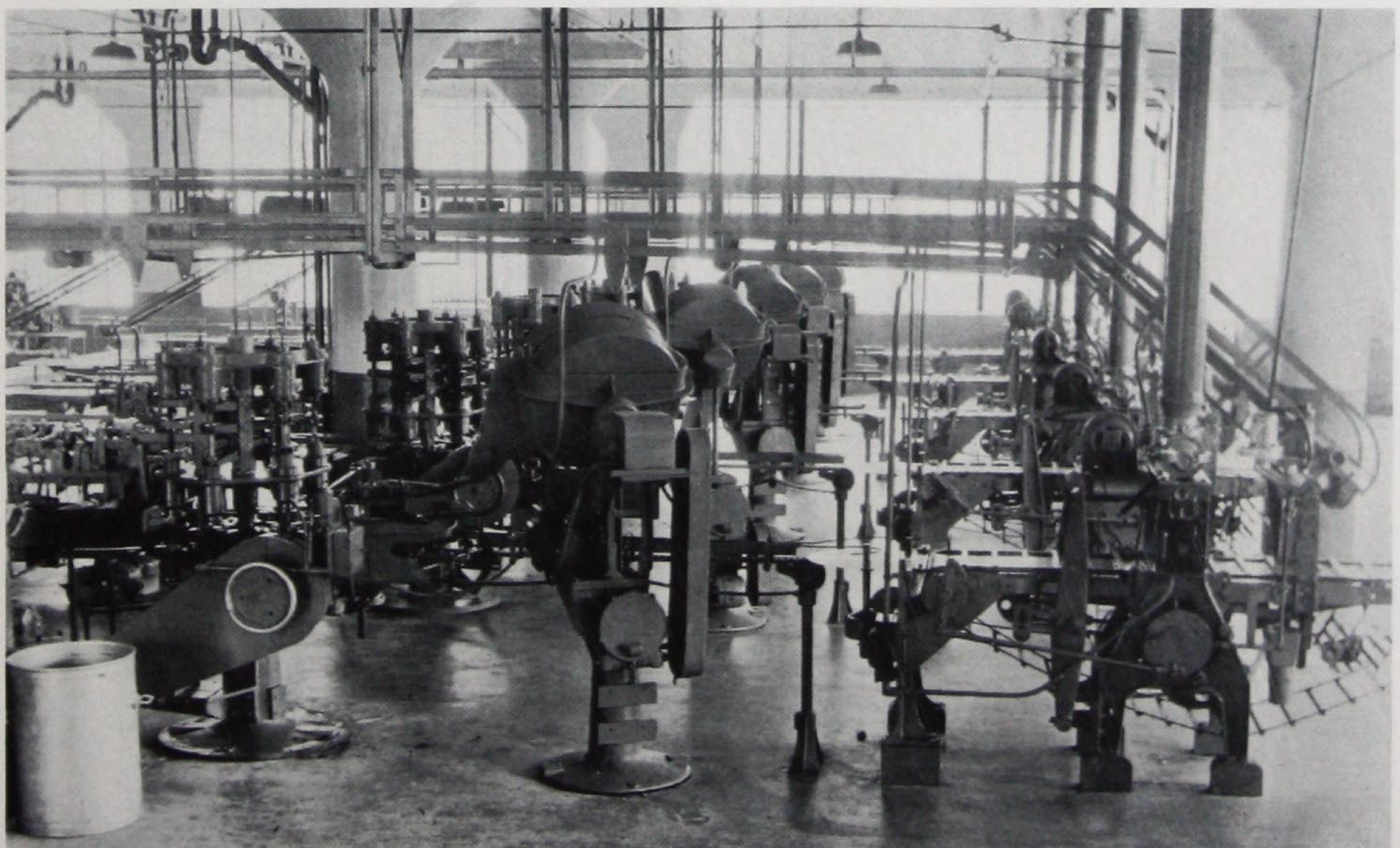
1. Permanence in the Atmosphere—At the ordinary natural temperatures, the atmosphere, with its usual traces of corrosive gases and variable moisture, leaves no evidence of attack upon the surface of U S S 18-8.

2. Resistance to Chemical Solutions—A large variety of industrial solutions and liquids have no effect upon U S S 18-8. To make unqualified predictions as to the action of various reagents upon the stainless steels is, in general, not a reliable procedure; service tests should be made to determine the performance of the material under actual conditions.

3. High Temperature Resistance—This property generally means resistance to oxidation at elevated temperatures, but also implies high temperature strength. U S S 18-8 has outstanding creep strength at elevated temperatures and, in addition, oxidizes very slowly once a thin adherent scale is formed. In cases where the gaseous or dry attack is not from the ordinary atmosphere, but from corrosive gases, appropriate exploratory tests should be made. U S S 18-8 scales comparatively little below 1600 to 1650°F.

Recommended Procedures for Use of USS 18-8

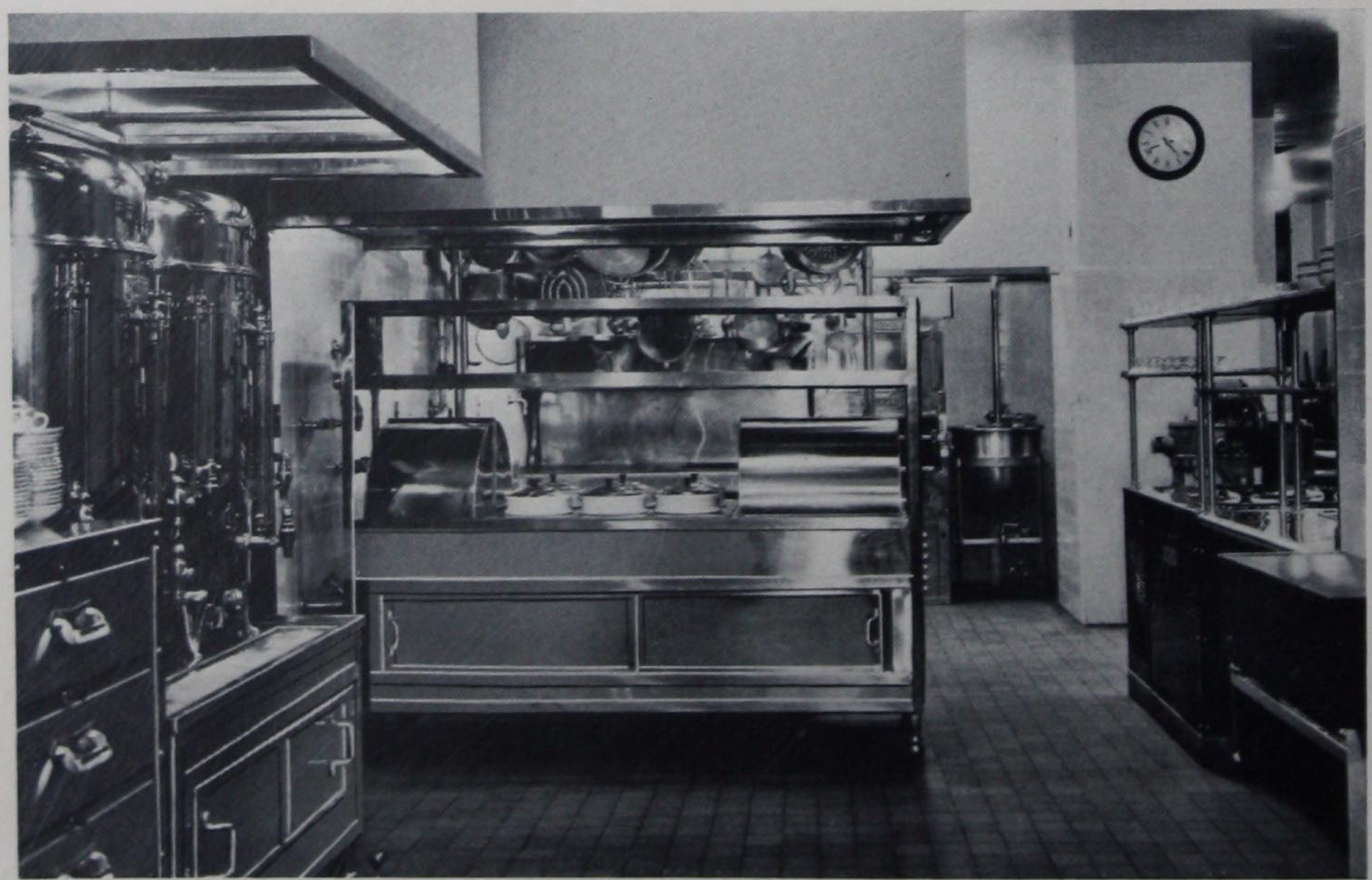
1. Forging—U S S 18-8 is a strong material; at elevated temperatures its strength is so superior to that of iron and low carbon steel that it forges much more slowly, and less reduction will result from the usual blows under the hammer. It may be



The smooth, non-tarnishable surface of U S S Stainless Steel makes it an ideal material for the construction of various food-handling equipment

forged at temperatures between 2200 and 1800°F., but light blows of the hammer should be used at the start. Heating, which requires a longer time than is allowed for ordinary steels, should be done slowly until a temperature of 1500 to 1600°F. is reached; then more rapidly to full forging temperature. Soaking at the full forging temperature should be avoided. It is advisable to reheat when the work cools down to 1800 to 1750°F., rather than to attempt much deformation of the stiff metal below this temperature.

2. Annealing—Since U S S 18-8 is not hardenable by heat treatment and does not undergo transformations upon cooling, the term "annealing," as here applied, has a somewhat different significance from that usually understood. Annealing U S S 18-8 is accomplished by heating to at least 1850°F. and then cooling rapidly. This treatment produces a completely austenitic structure of minimum grain size which, for numerous applications, is most desirable. Maximum ductility or softening is obtained by heating to about 2050 to 2150°F. and cooling rapidly. For heavy sections the rapid cooling should preferably be obtained by quenching, while in the case of light sections it is sufficient to air cool. The function of the anneal in the case of U S S 18-8 is to remove cold work effects, homogenize the structure, and dissolve any carbide particles which may have separated out within the metal at some intermediate temperature. By proper annealing, the metal is restored to the condition in which it has the maximum ductility and softness. It is advisable to cool from the annealing temperature as rapidly as possible, since no harm results from the most drastic quench.



U S S Stainless Steel kitchen equipment in a New York City bank

The chromium-nickel stainless steels should not be allowed to remain long at temperatures between about 1000 and 1600°F. as a *final* treatment, nor should the metal be allowed to cool slowly through this range except when it will subsequently be reheated to a temperature above 1850°F. This requirement eliminates any possibility of annealing 18-8 in the manner commonly followed with the plain carbon steels, which are annealed by heating to a relatively low temperature and cooling slowly. In the case of severely corrosive conditions, 18-8 that has been so treated will have its resistance impaired to a degree dependent upon the length of time it was subjected to the damaging temperature and the nature of the corroding medium. Under such conditions, attack will take place intergranularly; the application of a severely corrosive condition such as pickling sometimes resulting in complete disintegration.

U S S 18-8 is less susceptible to this impairment or deterioration than were the earlier "18 & 8" alloys; nevertheless, for complete realization of the inherent permanence of the alloy, the rule against the 1000 to 1600°F. temperature range should be observed.

Exceptions to this statement are explained in the chapters dealing with the alloys U S S 18-8S and U S S Stabilized 18-8, and should be referred to in this connection.

3. Welding—U S S 18-8 is not air hardening, and consequently yields ductile welds by electric resistance, electric arc, or acetylene torch methods, provided certain precautions are observed. It cannot be hammer welded successfully. Gen-

U S S Stainless Steel kitchen equipment in a prominent Eastern college

erally, resistance or arc welding will be found the more convenient, except for very thin sections, on account of the greater ease in controlling certain important operating conditions. However, a little practice will enable a competent welder to secure excellent results with this alloy by either gas or electric methods. A welding rod of low carbon U S S 18-8 should be used.

For gas welding: Be sure the surfaces to be welded are clean and free from scale.

Use only sufficient oxygen to insure a non-carburizing atmosphere around the hot metal. Maintain the flame as small as possible, and practically neutral. An oxidizing flame produces unsound welds, while a carburizing flame (one containing an excess of acetylene) produces brittle welds having a low order of corrosion resistance.

Direct the flame toward the unfinished work, thereby preheating.

Weld straight ahead and do not "puddle."

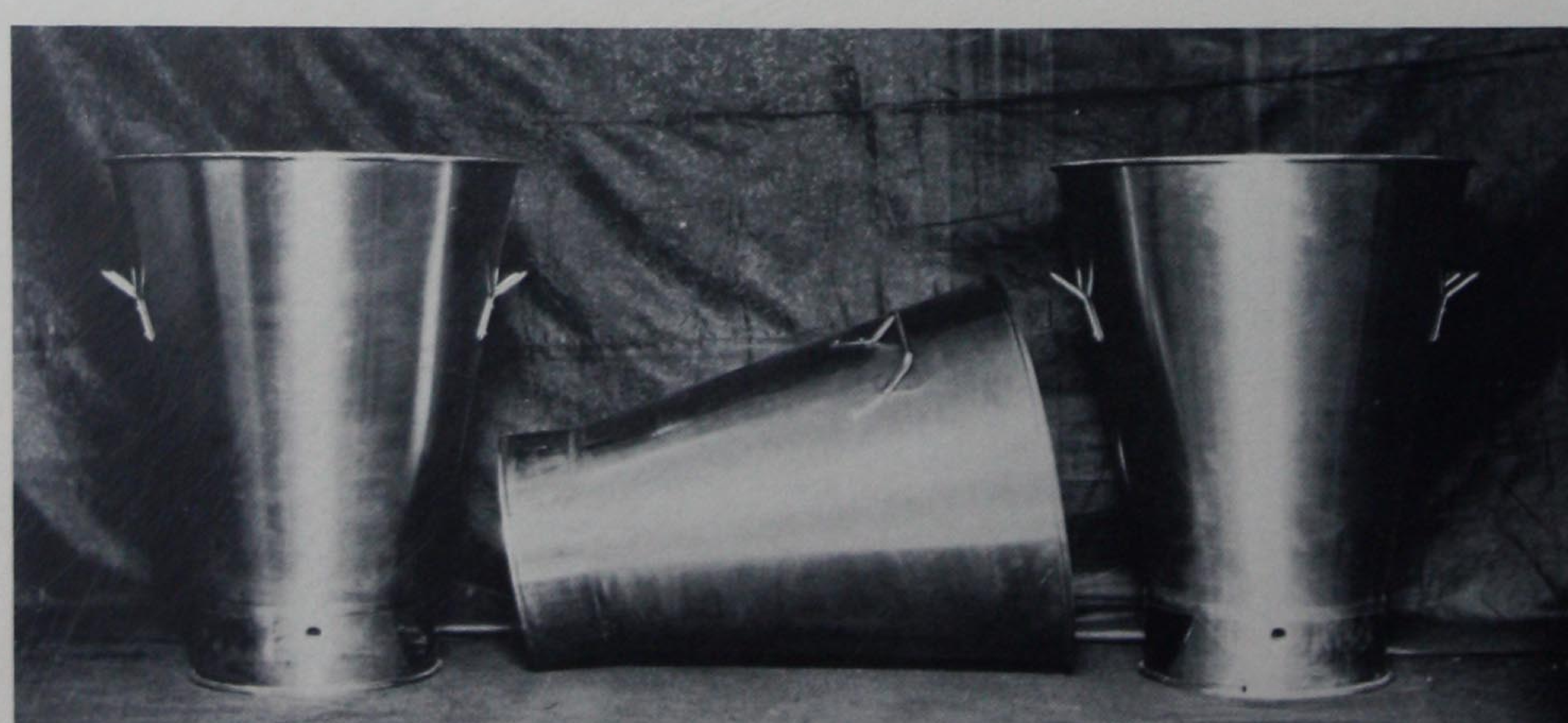
Use an uncoated welding rod of diameter about equal to the thickness of the material being welded, except for thicknesses over $\frac{1}{4}$-inch, for which $\frac{1}{4}$-inch rods may be used.

For arc welding: Be sure the surfaces to be welded are clean and free from scale.

The electrode is positive; the work negative. Proper regulation of the current is readily obtained after a familiarity with the welding characteristics of this alloy has been gained. About 35 volts (open circuit) with 60 to 65 amperes is generally satisfactory for a $\frac{3}{32}$-inch rod; the current increasing with the rod diameter.

Use a coated rod of diameter about equal to the thickness of the material being welded. The coating should not contain carbon in a form which may be absorbed readily during the welding operation.

It is preferable to lay several medium beads, with intermediate cleaning away



Whipped cream hoppers made of U S S Stainless Steel

of the slag formed, rather than to attempt to weld with a single heavy bead. The cleaning is best accomplished by light hammering with a blunt tool, or with a stiff wire brush.

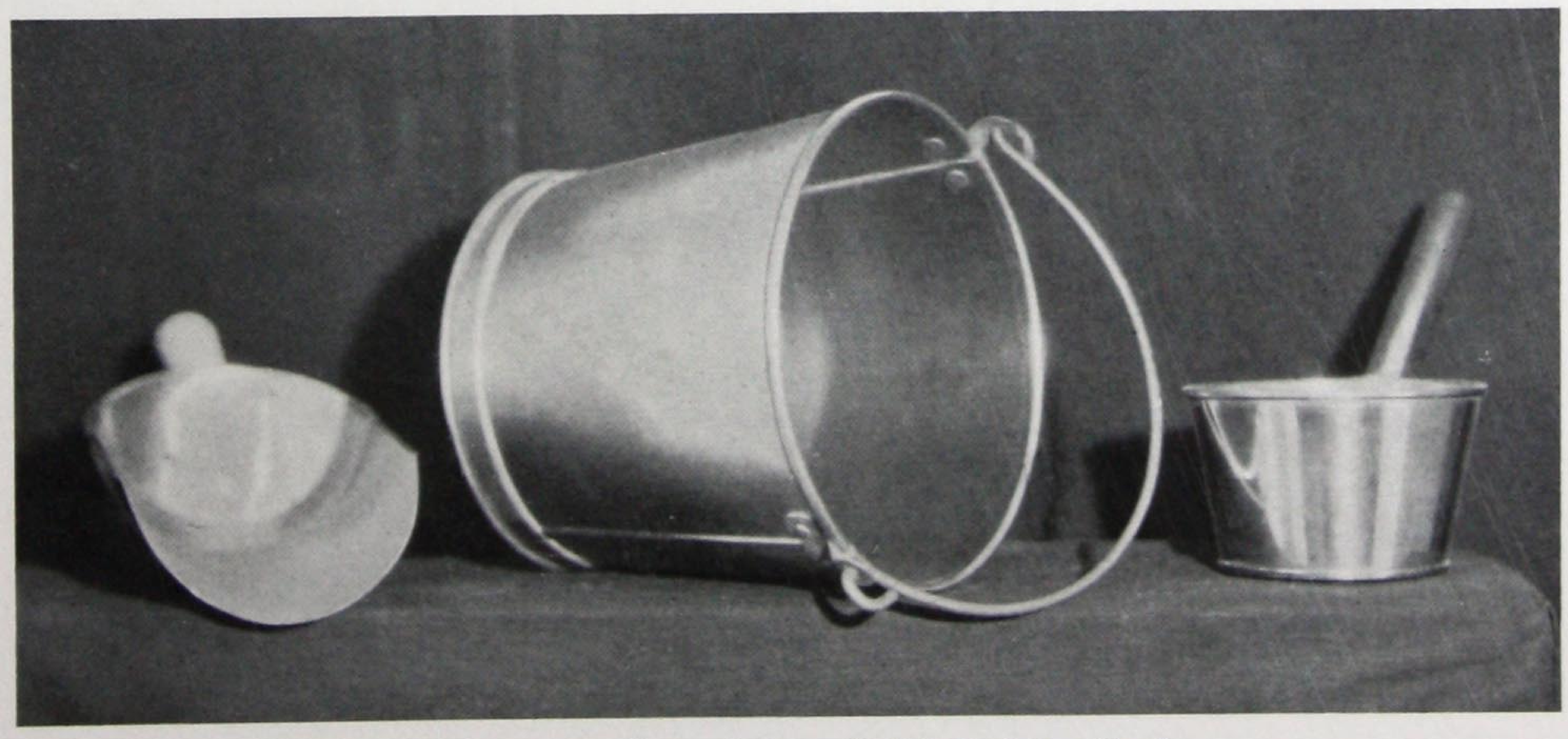
For resistance welding: The usual spot and seam welding processes may be readily applied to this grade of steel.

Welds of U S S 18-8 have satisfactory physical properties, but since during welding the metal is exposed to intermediate temperatures, the welds (and especially the metal adjacent thereto) may, in general, not possess maximum corrosion resistance. Hence, wherever feasible, the welded article should be annealed as indicated under "Annealing," if it is to withstand the most severe forms of corrosive attack.

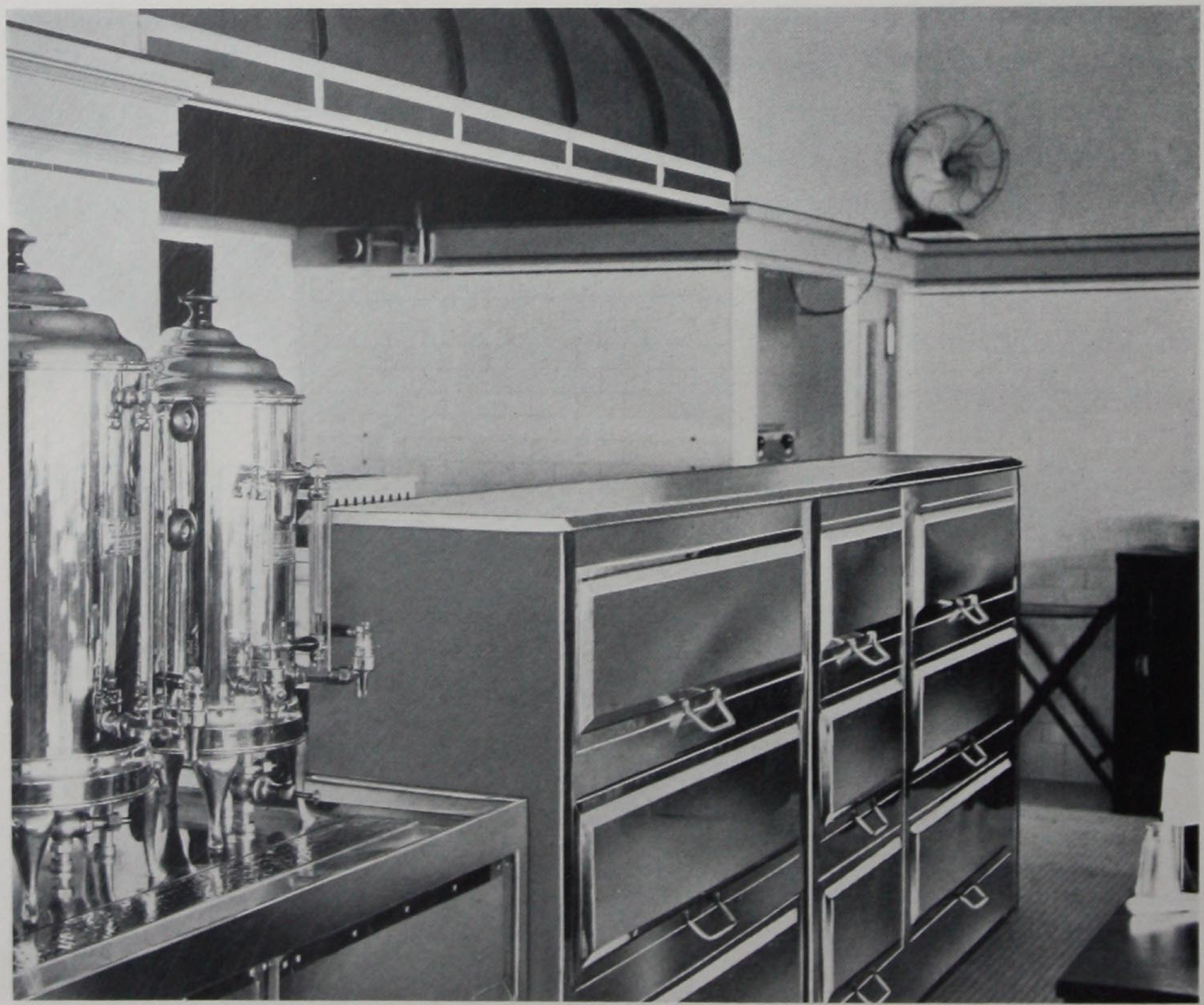
The U S S 18-8S and U S S Stabilized 18-8 alloys are the exceptions here also, as mentioned previously under "Annealing," and the chapters dealing with these alloys should be consulted.

4. Forming and Deep Drawing—U S S 18-8, while a more ductile metal than ordinary steel, is at the same time a stronger material, work hardens more rapidly, and accordingly requires more power in forming operations. In general, slower speeds are advisable, especially in the case of equipment originally designed for the softer materials. Solid steel dies are preferable; the deep hardening, non-deforming types of alloy tool steels being well adapted as die steels for forming U S S 18-8. Extremely well polished dies are the most satisfactory. A clearance about twice that used for ordinary steel or brass is usually considered good practice. Dies should be designed with the allowance for spring-back two or three times that for ordinary steel.

Forming and drawing operations on U S S 18-8 demand effective lubricants. From several standpoints, the so-called water-soluble drawing compounds are quite satisfactory. Linseed oil mixed with whiting and sulphur, as well as litho-



Modern utensils made from U S S Stainless Steel



Upper—*U S S Stainless Steel adds beauty, ease of sanitation, and permanence to this unique restaurant equipment in Hollywood, California*

Lower—*Warming cabinets made of U S S Stainless Steel in coffee shop of prominent Western hotel*

pone, are effective lubricants in some operations. The lubricant should be removed from the stamped articles after forming is completed.

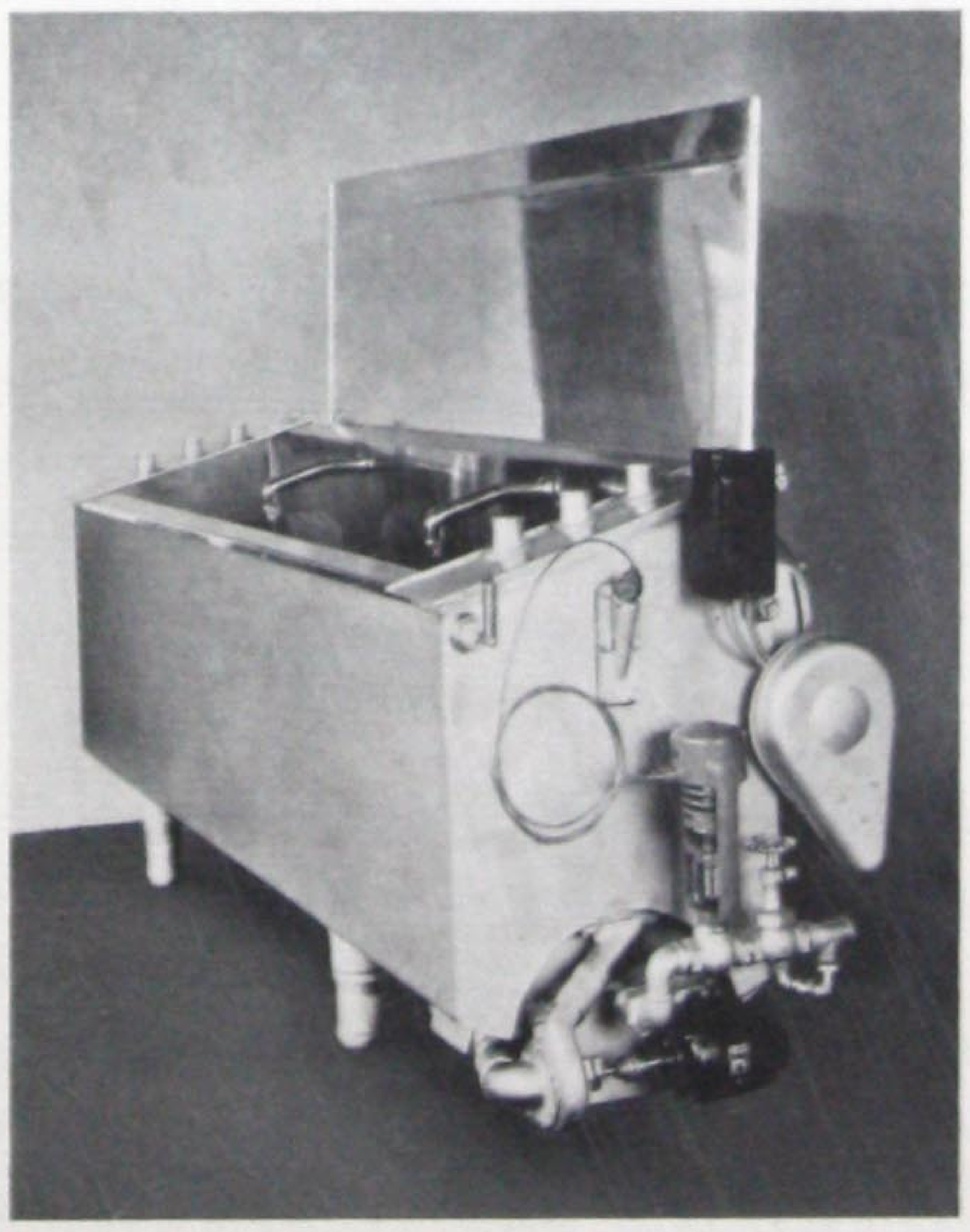
Forming operations are best applied to annealed U S S 18-8. Severe draws are possible without intermediate annealing, but whenever annealing becomes necessary the lubricant must first be removed, hence the necessity of considering this factor in the choice of lubricant. If not cleansed the metal will become contaminated (particularly carburized) by the decomposing lubricant, and its final properties and surface appearance may be impaired.

After annealing, which should consist of heating to 1850°F. or above, and quenching in water (or air cooling in thin sections), the metal should be pickled before continuing with the forming operations. This cycle may be repeated as often as necessary.

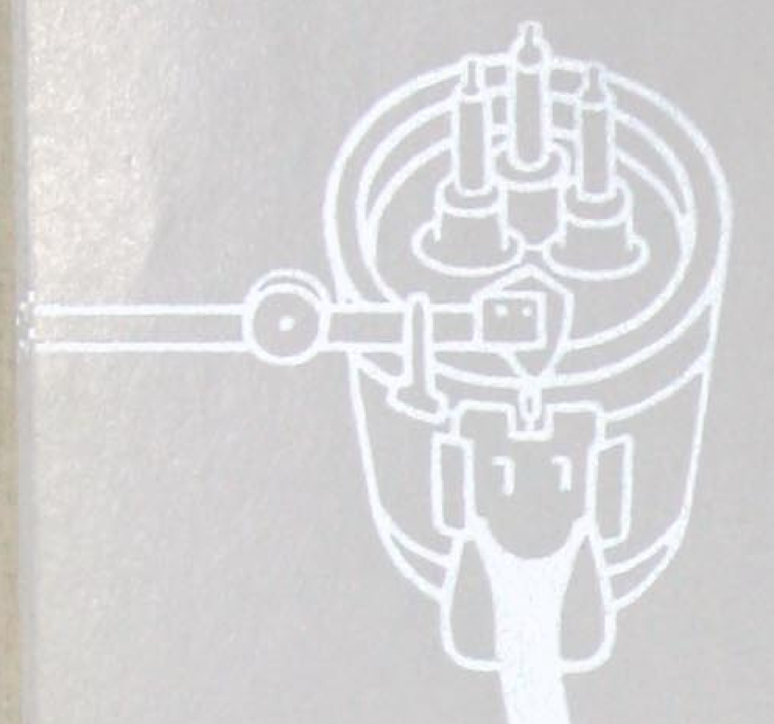
The adaptation of U S S 18-8 for cold forming operations is materially facilitated by a pre-warming of the blanks or dies, or both, to a very moderate temperature, such as 300 to 500°F., or any temperature which will not act to soften the dies by tempering. Working in this manner is accompanied by less hardening during deep drawing operations and may suffice to eliminate an annealing operation. This procedure is covered by a process patent assigned to the United States Steel Corporation.

5. Riveting—U S S 18-8 lends itself readily to either hot or cold riveting. Small rivets, up to about 3/8-inch, may be driven cold, and are set most advantageously by a comparatively few heavy blows. Hot rivets should be heated out of contact with flame to a temperature of 2100°F., and be set rapidly so that mechanical deformation is finished before they cool below 1800°F.

6. Spinning—Owing to the high ductility of U S S 18-8, it is well adapted to spinning operations. Being a strong metal and one which grows stiffer with cold work, it will require more power than is needed for brass. The spinning tool should have a fairly large radius, and the operation should be conducted at definitely slower speed than is customary with softer materials. When the total deformation exceeds that which can be accomplished in one operation, the work should be annealed, as outlined previously, and pickled. This involves removing the lubricant, and accordingly the water-soluble lubricants are most convenient. The thin



Spray pasteurizer lined with Stainless Steel



sections employed in spinning can be heated very quickly and need be held in a muffle furnace for only about 5 minutes, followed by a quick cooling in the air or a water quench.

7. Pickling—A hot pickling solution is required for U S S 18-8. The temperature should be approximately 150°F. Either hydrochloric (muriatic) acid or its equivalent (sulphuric acid and common coarse salt) is used. Sulphuric acid alone may be too slow in action to be practical.

It is customary to employ a solution made by mixing equal volumes of commercial hydrochloric acid and water.

Where sulphuric acid and rock salt are used, 10% sulphuric acid and 10% salt, heated to approximately 180°F., is satisfactory.

Nitro-hydrofluoric acid may also be used; a mixture of 10% nitric acid and 1 to $1\frac{1}{2}$% hydrofluoric acid, used at 125 to 130°F., will be found satisfactory.

A bright finish is secured by adding a small amount of nitric acid to the hydrochloric acid pickling solutions. The usual bright pickle solution consists of 4 volumes concentrated hydrochloric acid, 4 volumes water, and $\frac{1}{2}$ to 1 volume concentrated nitric acid. Heavily scaled articles should be pickled in a solution consisting of 8 volumes concentrated hydrochloric acid, 7 volumes concentrated sulphuric acid, and 15 volumes water, prior to using the bright pickle solution.

It is advisable to add a suitable inhibitor to the solutions used for pickling stainless steels. A number of satisfactory inhibitors are readily available commercially.

After all pickling operations the pickling acid should be rinsed off in hot water and the work then be given a few minutes in hot 10 to 20% nitric acid (about 125 to 140°F.), followed by a wash in hot water.

The ideal tank for the nitric acid dip solution is one made of U S S 18-8, or one lined with this metal.

8. Passivation of Finished Articles—During machining, riveting, forming, polishing, etc., foreign particles may become embedded in the surface of the stainless steel, and unless these are removed they will subsequently lead to rust spots. To avoid this potential source of trouble, the finished article should be swabbed or immersed for a few minutes in hot 10 to 20% nitric acid (about 125 to 140°F.), followed by a wash in hot water, as mentioned under "Pickling." This treatment insures the restoration of the protective surface film, upon which rustlessness depends.

9. Operations Involving Cutting—

A. *Sawing*—U S S 18-8 is not cut with the same ease as ordinary annealed steel, nevertheless it is satisfactorily cut by the saw. A high speed steel saw, rather heavily weighted, should be used and so applied that the first stroke definitely cuts the metal. If the work heats it will cut somewhat better. A wavy set

saw is particularly well chosen for this metal. It is disadvantageous to permit the saw to ride over the work without cutting, as this quickly work hardens the U S S 18-8 locally, and renders the operation much more difficult.

B. *Machining*—The art of cutting U S S 18-8 may be summed up by the recommendations—(1) slow speed, (2) heavy cut, (3) sharpest tools, (4) generous rake. If the work warms up considerably, the cutting is easier. It may be machined dry or with lard oil-sulphur lubricant.

C. *Drilling*—Drilling involves the same considerations as machining. Use a very sharp drill—preferably of high speed steel. Make the drill cut all the time, but remove and cool occasionally. The work should be backed up so that the drill cuts through without punching out the last metal. If a lubricant is required, the lard oil-sulphur mixture is effective.

D. *Threading*—The same general rules apply as for other machining operations. A four- or five-thread lead is advisable.

10. Punching and Shearing—As a further adjustment to the very great toughness and elongation of U S S 18-8, the engaging parts employed for shearing and punching must fit more neatly than those used for ordinary steel; otherwise, metal may drag between the punch and the die. In punch work it is necessary to punch all the way through the stock, in order to obtain clean edges and clean parting of the metal. Shear blades must press together closely.

11. Soldering—Notwithstanding the protective character of the surface of U S S 18-8, it may be soldered, provided a sufficiently strong agent be used to develop a clean metal surface. The hydrochloric acid-zinc chloride combinations (muriatic acid cut with zinc) are effective. Polished surfaces are more resistant to etching by the soldering fluid and, therefore, some little time should be allowed. Care should be taken to prevent the contact of flux with metal away from the seam, and any excess should be removed by thoroughly scrubbing and washing the finished articles, using a mild alkali solution.

Because of the ease of welding U S S 18-8, and the possibility of deleterious effect on the metal, it is, in general, inadvisable to braze, although brazing is easily accomplished.

12. Polishing—The methods of polishing U S S 18-8 vary so greatly with the nature of the articles that it is impossible here to give any detailed instructions. Therefore, only a few general suggestions are offered.

The most suitable abrasives are those of the silicon carbide or aluminum oxide type. They should be used on a soft grease wheel. Stearic-base grease is preferable to the petroleum-base grease on account of its higher softening point. In general, dry grinding should never be used and, for obvious reasons, iron oxide polishing compounds should not be applied to the stainless steels.

Grinding speeds should not exceed 8,000 feet per minute, although final buff-

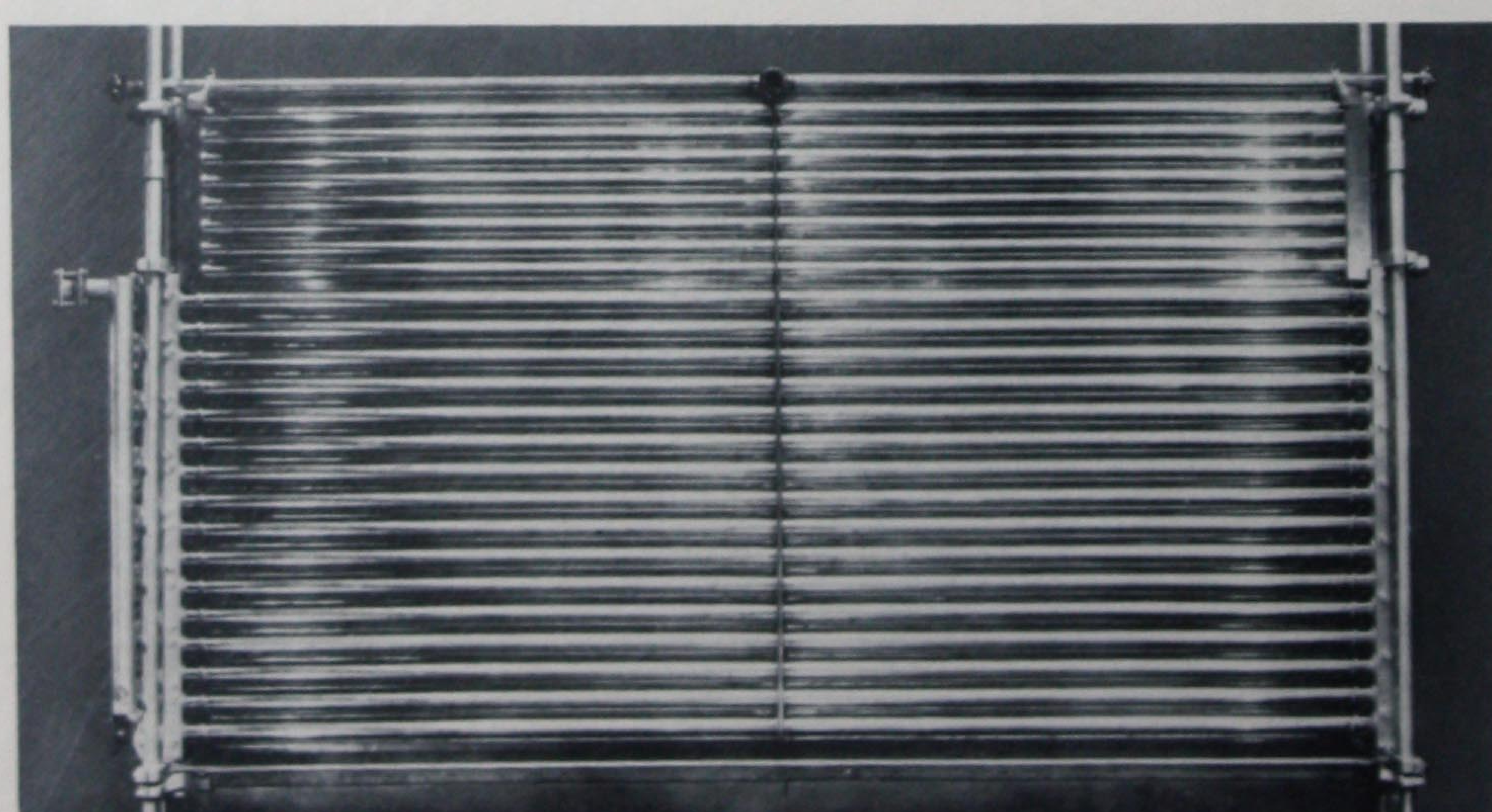
ing speeds may reach 10,000 feet per minute without damage. Higher grinding speed roughens the surface in a characteristic manner. In general, after the last grinding, it is advisable to brush before buffing.

Metallurgical Nature of USS 18-8

Some of the aspects of working and heat treating U S S 18-8 differ markedly from the corresponding processes of handling ordinary steel. It is sometimes suggested that a new metallurgy has come into existence with the new rust resisting steels. If so, it is a metallurgy of steels having very high alloy and very low carbon contents. In order to gain a simplified conception of the nature of U S S 18-8, it may be expedient to inquire into the physical metallurgy of the alloy.

Significance of Austenite—In contrast to some others of the series of U S S high chromium stainless and heat resisting steels, U S S 18-8 is practically non-magnetic, and is an austenitic alloy. This circumstance is of considerable importance in that many of the outstanding properties are definitely dependent upon that structural condition of iron alloys designated by the name "austenite." The metallurgical conception of austenite may be expressed briefly somewhat as follows:

Iron, and carbon steels, may exist in two forms; the prevailing form depending upon the temperature. Above the critical temperatures, iron assumes a crystal form designated as "gamma" iron; the carbon, and other elements, being dissolved in this gamma iron to form austenite. The crystal form of austenite is that found in all the very ductile metals, such as gold, copper, nickel, and aluminum. The crystal of austenite is identified with high ductility. Below the critical range, or temperature of transformation, iron assumes the form designated as "alpha" iron,



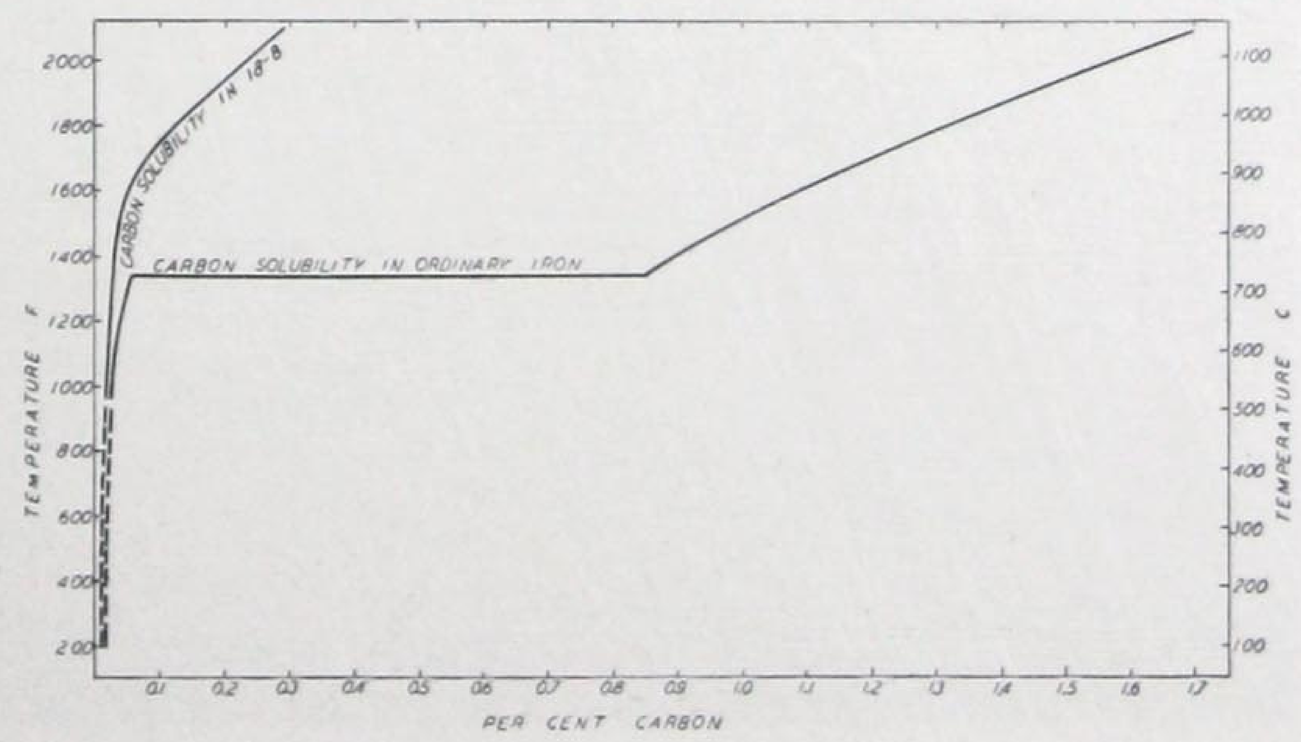
Stainless Steel Tubing offers distinct advantages for the construction of coolers, condensers, etc.

and rejects carbon as carbide. The chromium (if any is present), as well as other elements, may remain in solution, and the solution is known as ferrite. But the crystal form of ferrite is that of tungsten, molybdenum, and chromium, and is, accordingly, a less ductile crystal form. Iron is magnetic only in the form of ferrite.

As might be expected, chromium by itself tends to obliterate the austenitic form in iron alloys, while nickel exerts a strong influence to preserve the austenitic form, even down to ordinary temperatures. Thus in U S S 18-8 we find the nickel dominant in preserving its very ductile austenitic condition, even in an alloy carrying approximately 18% chromium. The degree of stability of this austenitic condition is partly dependent upon the nickel content, and in U S S 18-8 this is carefully adjusted to produce the alloy best suited to a designated purpose.

Cold Working—Except when the nickel content is very high, the austenitic alloy begins to transform slowly as the metal is deformed in any of the various working operations. In brief, this transformation is from austenite to ferrite of a form possessing great strength and considerable hardness and, in addition, a form having essentially the same resistance to corrosion as the austenite. This circumstance permits the development of amazing tensile strengths by cold work. Over 400,000 lbs. per sq. in. may be developed in cold drawn U S S 18-8 wire. If the annealed, and therefore wholly austenitic, metal is not deformed in the cold, it is completely permanent and remains non-magnetic; but with cold deformation, the alloy gradually develops a response to the magnet in proportion to the transformation brought about by the cold work. While U S S 18-8 is surprisingly ductile, it nevertheless hardens under deformation more rapidly than those metals which do not undergo transformation during cold work. It should be mentioned that, notwithstanding the transformation of austenite to ferrite during cold work, no carbide is precipitated and, as a result, the austenitic alloys of high carbon content harden more rapidly during cold work than those of low carbon content, even though the transformation is less.

Carbon Solubility—An example of a somewhat radical departure from the familiar behavior of carbon steel is observed in connection with the carbon solubility of U S S 18-8. At a temperature of about 2100°F. carbon steel can carry 1.7% carbon in complete solid solution, i.e., it will be free from carbide particles. At the same temperature, U S S 18-8 can absorb only about 0.30% carbon in this manner. The carbon solubility is shown in the accompanying curve.

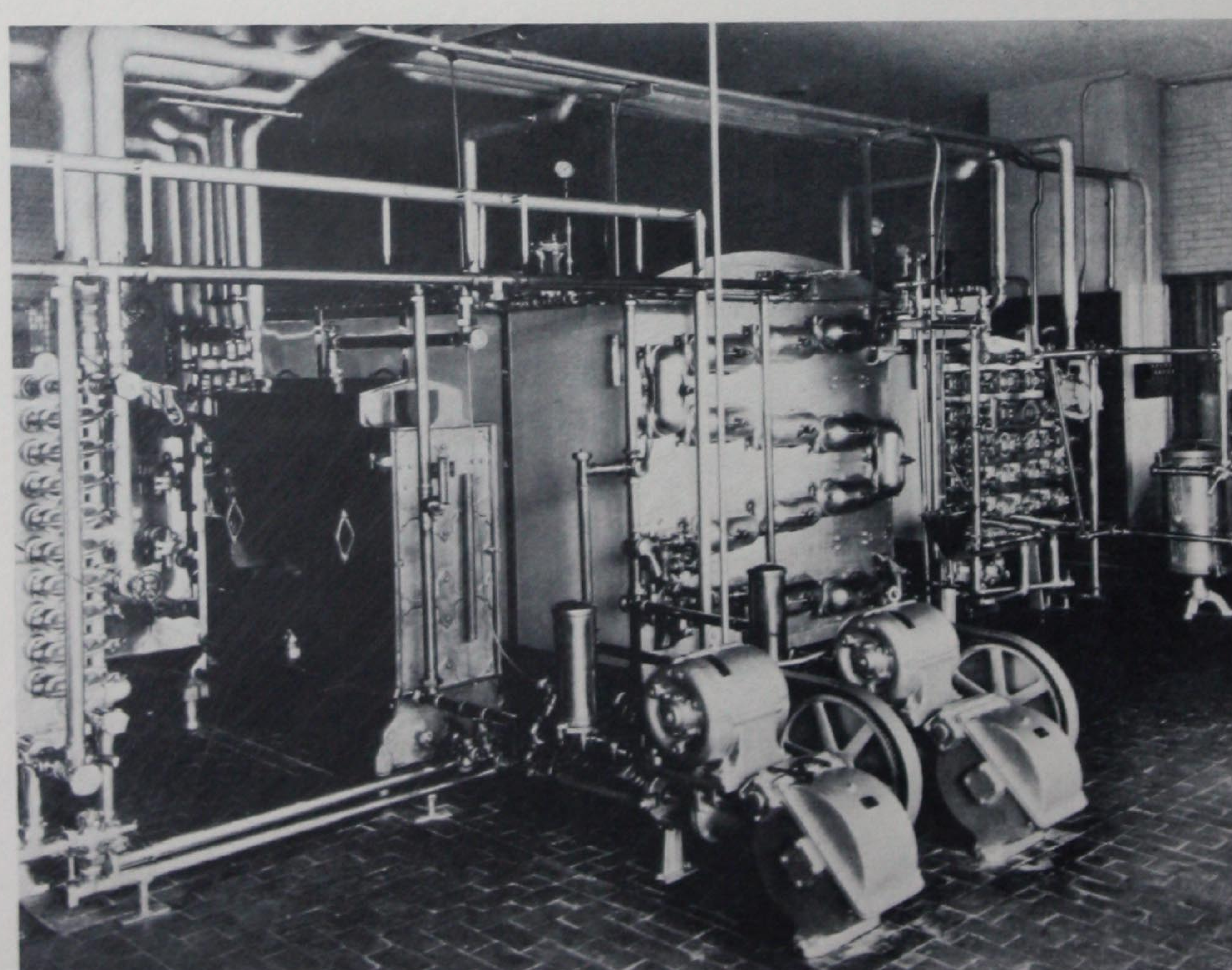


If the metal is heated to any temperature at which the whole

of the carbon content will dissolve, the carbide is not reprecipitated upon subsequent rapid cooling; but when the cooling is slow, the carbide is generally formed at the grain boundaries to a size visible under the microscope. The carbide of U S S 18-8 appears to be of approximately the composition Cr_4C. Obviously, its formation withdraws a rather high proportion of chromium from the austenite proper. In general, this is of small practical import, except in cases where the material is to be welded, or will be subjected to the damaging temperature range (1000 to 1600°F.) mentioned before. For such purposes, U S S 18-8S or U S S Stabilized 18-8 should be used, the choice depending upon the nature and severity of the corrosive conditions to be encountered.

Annealing—The brief heating of U S S 18-8 to 1850°F. or higher, after either cold working or an inadvertent exposure to the temperature range 1000 to 1600°F., completely accomplishes removal of stresses, recrystallization, and full softening, as well as carbide solution. The metal is then homogeneous, soft, and ductile, and possesses the inherent high resistance to corrosive attack.

Metallographic Examination—A few words relating to the polishing and etching for microscopic examination of U S S 18-8 are appended for the particular attention of metallographists.



The pasteurizer, as one of the most important pieces of dairy equipment, should be adequately safeguarded by the use of Stainless Steel

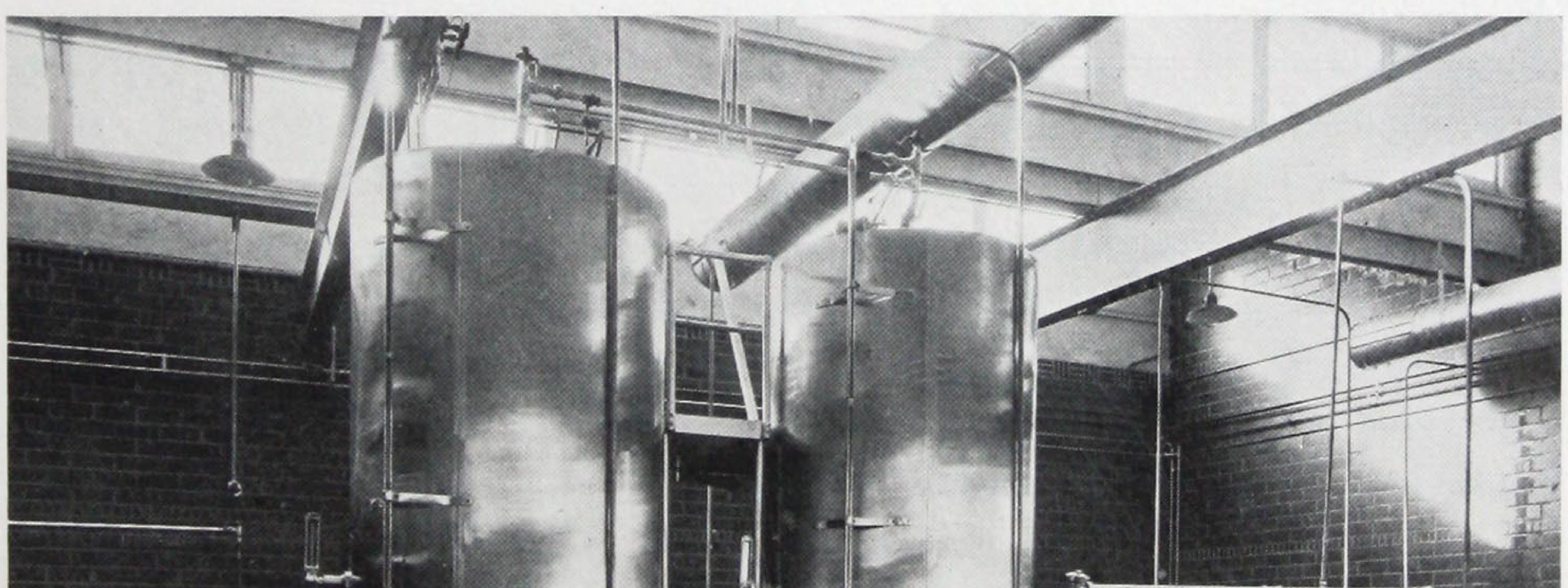
In cutting off samples for microscopic examination, it is imperative that the metal be deformed as little as possible. Moderate deformation, such as results from clamping in a vise and sawing, usually suffices to produce prominent slip bands which are not inherent in the metal itself. The rubber-carborundum cutting wheels are very satisfactory, and various other means of avoiding disturbed metal in the surface to be polished will suggest themselves. The ordinary succession of abrasive papers will, in themselves, produce some disturbed metal; accordingly, a relatively longer time on the finest abrasives is necessary. It will be found necessary to alternately etch and polish on the final cloth about three times before an entirely representative surface is obtained, i.e., one free from surface disturbances introduced by the polishing itself.

Four types of structure are all that are likely to be found.

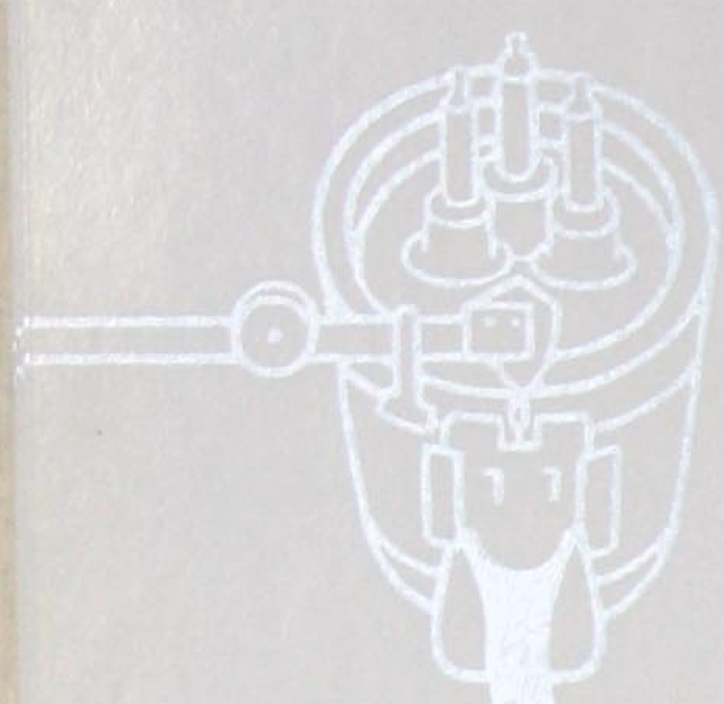
1. The annealed structure, identical with nickel, Monel, and certain other metals having the twinned-grain characteristics.

2. The cold worked structure, similar to cold worked nickel, brass, Monel, etc., except that the cold worked austenitic steel reveals rather more prominent slip bands.

3. The annealed metal which has been mistreated by an exposure to the



With extra durability, Stainless Steel assures a high degree of sanitation in milk-measuring vats and other food containers



range 1000 to 1600°F., and therefore has darkly-etched grain boundaries. This appearance is easily recognized, and may serve as a warning of the possibility of intergranular attack.

4. The cold worked metal likewise heated at the intermediate temperature. In etching, this metal will darken rapidly over the entire surface, without regard to grain boundaries. This does not indicate a condition within the metal that makes it susceptible to strong intergranular attack, although a superficial darkening may result from this condition.

Considerably more patience and skill are necessary for the preparation of microscopic samples of any of the stainless steels than are required for specimens of ordinary steels.

USS 18-8S

As will probably have been surmised, the grain boundary precipitation phenomenon that takes place upon heating U S S 18-8 in the temperature range 1000 to 1600°F. is almost entirely due to carbon. It is perhaps obvious that if U S S 18-8 contained no carbon whatever, heating in the damaging temperature range would have no effect. Conversely, increasing the carbon content magnifies the effect proportionately. The particular kind of corrosive condition to which the metal is exposed also plays an important part in making evident this condition of the metal. An intermediate step to inhibit intergranular corrosion is to limit the carbon content to some definite maximum; thus controlling the amount of carbide precipitated, and lessening the susceptibility to attack.

U S S 18-8S is a modification of the U S S 18-8 analysis previously discussed. It was developed for the purpose of minimizing intergranular corrosion, and in this respect is satisfactory for a number of uses. Although it is not an alloy that can be relied upon to completely resist and give no evidence of such attack, it will withstand considerable temperature exposure and, unless the corrosive conditions are severe, it should give satisfactory service. The analysis is the same as that of U S S 18-8, except that the carbon content is never allowed to exceed 0.08%. The general corrosion resistance and physical properties are identical with those of U S S 18-8, and the instructions covering pickling, forming, annealing, etc., given for that alloy, apply equally well to U S S 18-8S.

USS 18-12

Another modification of U S S 18-8 is the alloy U S S 18-12, which contains considerably more nickel than the 18-8 composition. For certain specific applications, such as for cold working, this alloy is advantageous; the transformation of austenite to ferrite being almost entirely suppressed, and the rate of effect of cold working correspondingly decreased. Even the cold worked product is substantially nonmagnetic.

U S S Stabilized 18-8

U S S Stabilized 18-8, a modification of the regular 18-8 analysis previously discussed, is designed for maximum dependability after being welded or subjected to intermediate temperatures during fabrication or service. This alloy, which contains a special element in addition to chromium and nickel, when properly heat treated, exhibits complete freedom from intergranular attack even under the most severely corrosive conditions. It is now generally accepted that welding, with its attendant thermal gradient in the base metal adjacent to the weld, causes a precipitation of carbide in the grain boundaries of the regular 18-8 alloy, and a consequent depletion of chromium in those portions of the grains adjacent thereto. This depletion in chromium presents a vulnerable condition to the corroding medium, permitting ready attack, which in some cases may be so severe as to cause complete disintegration of the alloy. Disintegration may occur only in the metal adjacent to the weld or, when the entire piece has been subjected to an intermediate temperature of 1000 to 1600°F., it may be general over the entire piece. The above described phenomenon is characteristic of all straight chromium-nickel austenitic stainless steels. However, it has been determined that incorporation in the alloy of a strongly carbide-forming element such as titanium, together with a suitable heat treatment, will completely immunize the alloy from this intergranular deterioration. The stabilizing heat treatment applied to the titanium-bearing alloy forces the maximum combination of titanium and carbon, and so prevents impoverishment or depletion of the chromium content of the grains. The stabilized alloy is not damaged by heating in the temperature range 1000 to 1600°F., in which the regular 18-8 alloy may have its corrosion resistance seriously impaired. This stabilizing treatment is subject to patent for the exclusive use of the Subsidiary Companies of United States Steel Corporation.

Composition

With the exception of the stabilizing element, the composition of this alloy is essentially the same as that of the regular U S S 18-8, and it exhibits physical properties similar to those of the usual alloy. These physical properties are listed in the table on page 46.

Resistance to Corrosion

The terms "stabilized" or "stabilization," as employed in the naming of this alloy, refer primarily to the stability of the material in resisting intergranular attack under severe conditions of corrosion and temperature, as compared to the lack of stability, or susceptibility to attack, of the usual alloy. Designed, as already explained, as a particular alloy for use under a particular set of conditions, U S S

Stabilized 18-8 will, in general, exhibit corrosion resistance equal to that of the unstabilized alloy, although under certain conditions of corrosion it may be somewhat more susceptible to general surface attack than is regular 18-8. For this reason, when intergranular attack is not involved, the use of the regular U S S 18-8 is recommended, since the maximum resistance to general surface attack will be given by that alloy. However, for articles that might be subjected to intergranular attack, the stabilized alloy should be used; for even though it may be slightly less resistant to general attack, this feature can be readily sacrificed for the assurance that premature failure due to intergranular attack will not occur.

Since it is necessary for a particular heat treatment to be performed on this alloy, all U S S Stabilized 18-8 is so processed before shipment from the manufacturing Company, thus assuring that when received it will be in a condition satisfactory for immediate use.

Recommended Procedures for Use of U S S Stabilized 18-8

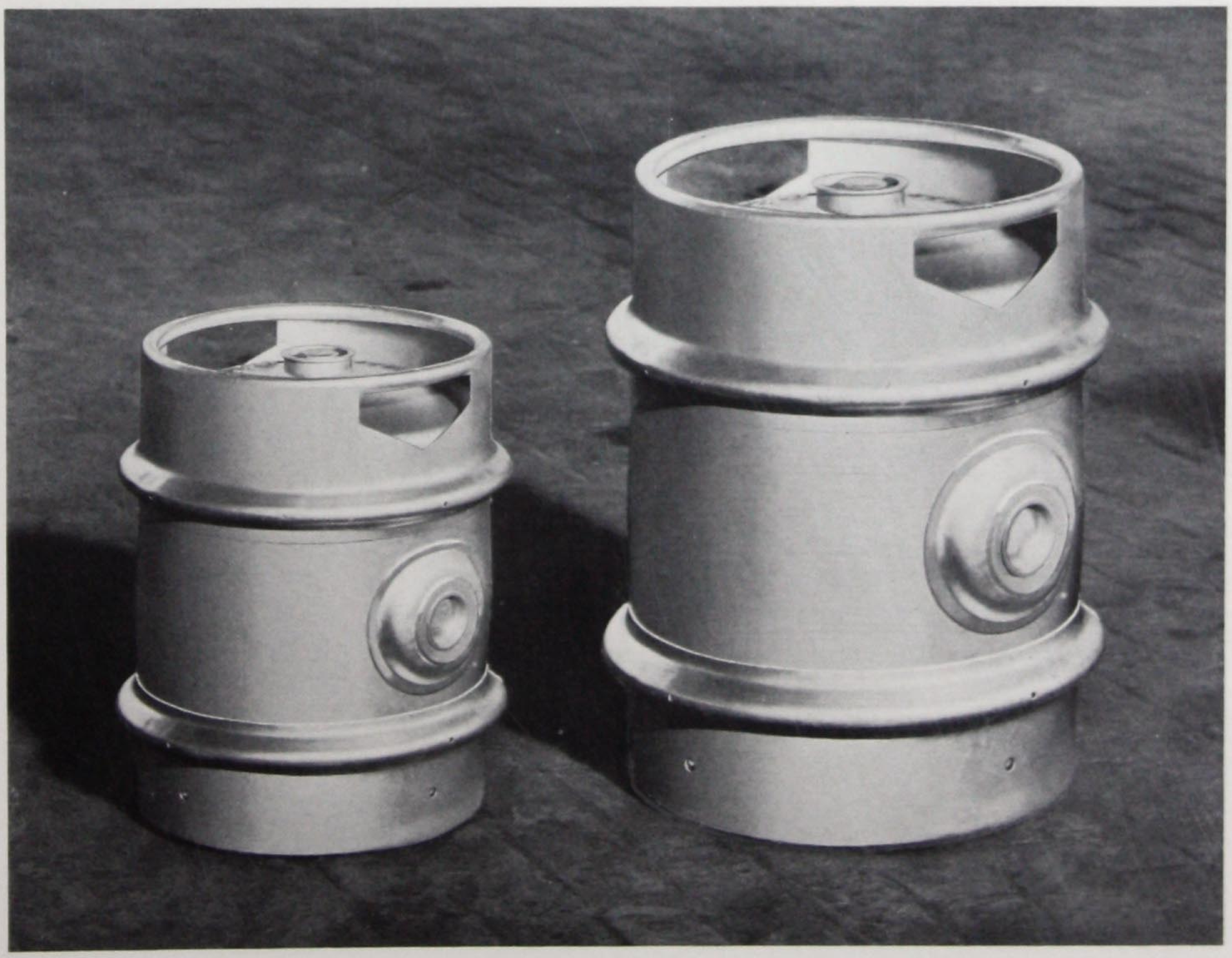
In general, forming, machining, etc. can be performed on the stabilized alloy in the same manner as on the regular 18-8; it is only necessary to adhere to the same general procedures outlined for that alloy. Welding is readily accomplished, and

U S S 18-8 (left) welded to U S S Stabilized 18-8 (right) and then etched. Note marked selective attack of the regular material adjacent to the weld, and freedom from such attack in the Stabilized alloy

the handling of the stabilized material is considerably facilitated by its being unnecessary to perform the high temperature heat treatment recommended for U S S 18-8. This facility is of tremendous advantage in the fabrication of articles that must resist intergranular attack, but the construction of which prohibits application of the heat treatment after fabrication. Flanging, Vanstoning, bending, and other hot operations which in the past, and as applied to the usual 18-8 alloy, have required a subsequent high temperature quench (1850°F.), can be performed and the material immediately placed in service without any further heat treatment. Certain precautions must be observed, however, in hot working and welding. Information for particular operations will be supplied upon application to the nearest Sales Office of the United States Steel Corporation Subsidiary concerned.

Forming and deep drawing, as well as other operations involving cold work, are performed quite readily on this alloy, and it can be annealed at a low temperature for stress relief—a practice not generally recommended with the usual 18-8 alloy on account of the danger of rendering the material susceptible to intergranular attack.

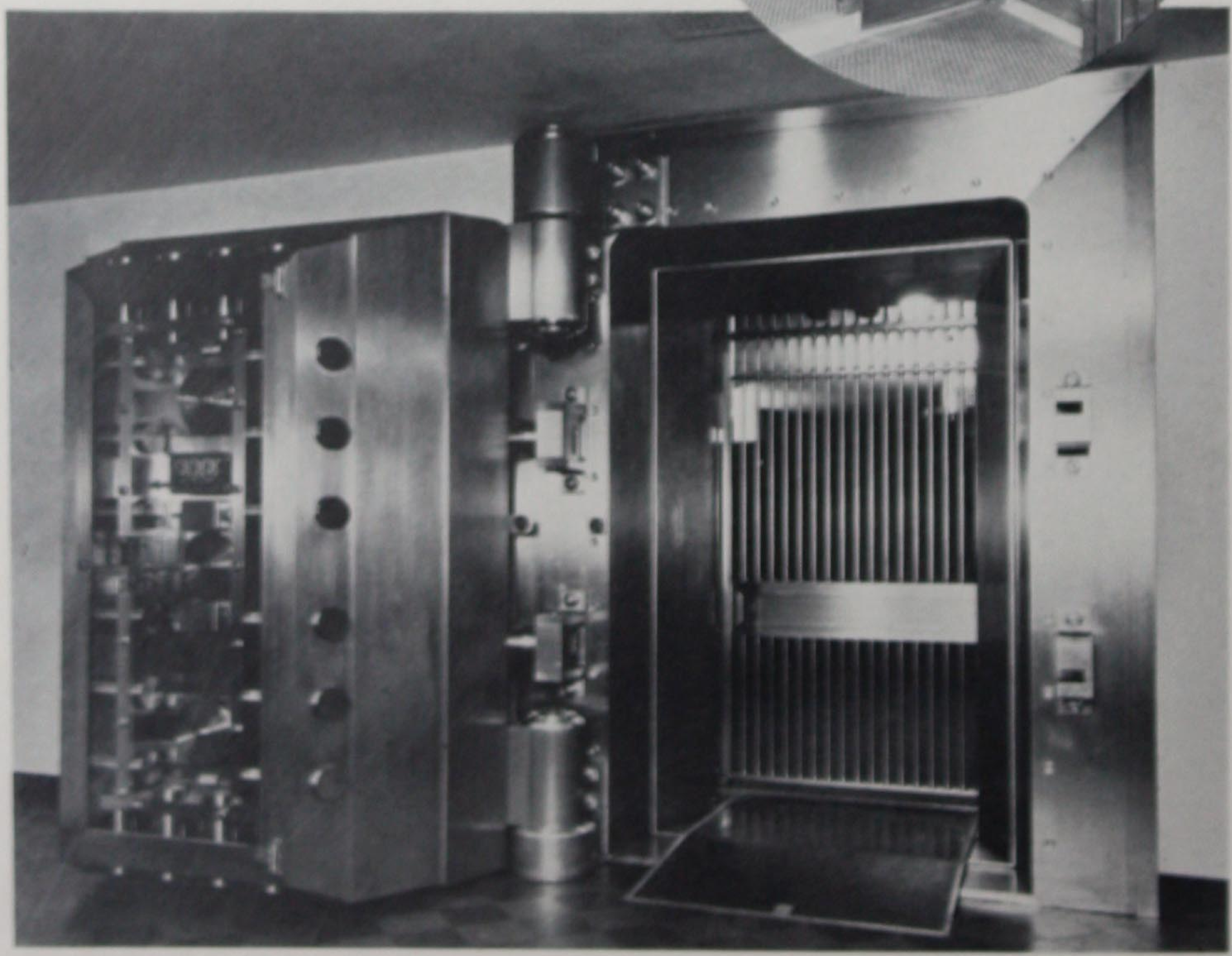
With the above exceptions, the general rules set forth for the forming and processing of U S S 18-8 apply also to this alloy.



Typical modern beverage-shipping containers made of U S S Stainless Steel

Upper and circle—*The entrance and lobby of this well known New York theater are greatly enhanced by the use of U S S Stainless Steel doors and trim*

Lower—*The rich, permanent beauty reflected by the use of Stainless Steel for this bank vault, is typical of many applications of this marvelous material*



USS 17

This alloy steel is entirely permanent in the ordinary atmosphere, provided the surface is well polished and free from foreign particles. It is a non-hardenable alloy which develops and retains its full corrosion resistance without any special heat treatment. It is ductile and malleable, and is suitable for all except the most severe forming operations, for which U S S 18-8 is preferable. It resists oxidation at elevated temperatures so effectively that it may be used continuously at temperatures as high as 1550°F. U S S 17 may be obtained from the Subsidiary Manufacturing Companies of the United States Steel Corporation in the form of bars, shapes, strips, sheets, plates, tubes, and wire.

Physical Properties

A satisfactory conception of the general characteristics of U S S 17 may be obtained from the table of properties on page 47.

It will be apparent that a metal with such physical properties will constitute an adequate material for a wide variety of applications in which its corrosion resistance makes it specially desirable.

Composition

Certain slight modifications in composition are made for special applications but, in general, the composition of U S S 17 will lie within the following limits:

Chromium	16 to 18%	Silicon	Max. 0.50%
Manganese	Max. 0.50%	Carbon	Max. 0.10%

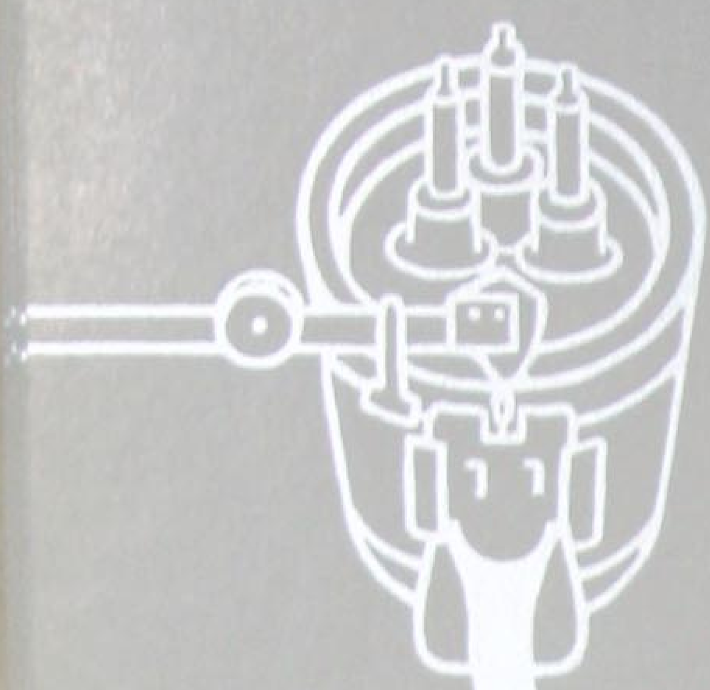
This metal, as a result of its low carbon and high chromium content, is a ferritic alloy and therefore magnetic. Except for higher strength, it is quite similar to low carbon steel in general physical nature.

Resistance to Corrosion

The corrosion resistance of U S S 17 is complete in a somewhat more restricted range of environments than that of the nickel-bearing U S S 18-8. However, the metal will remain untarnished in the ordinary atmosphere under the widest range of conditions when the following circumstances prevail:

1. Surfaces are properly cleaned and polished.
2. Water can quickly drain away, and drying ensue.
3. No considerable amount of dirt can accumulate. This, in general, implies that (1) and (2) are provided for. The deciding factor, as to whether U S S 17 will remain untarnished or not in certain severe conditions, may be the accumulation of dirt, for dirt accumulation provides tiny spots of active chemical reagents when evaporation gradually concentrates the liquid trapped by the foreign matter.

A conception of the type of resistance against chemical attack offered by



U S S 17 may be formed by a consideration of the following common materials which do not substantially affect the clean metal surface:

Acetic Acid, dilute
Alkaline Solutions, in general
Ammonium Hydroxide
Bleaching Powder (slight attack)
Boric Acid
Carbolic Acid
Citric Acid (slight stain)
Formaldehyde
Fruit and Vegetable Juices
Lactic Acid
Lemon Juice
Milk, sweet or sour
Mine Waters, in general
Nitric Acid
Nitrous Acid (slight stain)
Photographic Developers
Soap Solutions
Zinc Chloride (slight attack)

In general, it is not satisfactory to attempt predictions relating to the corrosion resistance of U S S 17 under untested or untried conditions. Inquiries regarding new applications should be addressed to the manufacturing Subsidiary Companies so that, if suitable information is not already available, appropriate tests may be conducted under service conditions.

Resistance to high temperature, in general, signifies resistance to oxidation, accompanied by retention of high strength. U S S 17 develops a thin protective scale which retards further oxidation up to a temperature of 1550°F. It is not much affected by moderate sulphur content in gases at high temperature. The creep strength at elevated temperatures is in excess of that of ordinary steels, as shown in the table of properties.

Recommended Procedures for Use of USS 17

1. **Forging**—U S S 17 should be forged between 2000 and 1600°F., but if much further reduction is to be accomplished after the metal has cooled to 1700°F., it will be found preferable to reheat rather than to work the stiff metal at a lower temperature. The *final* finishing temperature should not exceed 1600°F. and may well fall to 1300°F. in the case of well-worked metal. Heating much above 2000°F. may cause excessive grain growth. Heating is best accomplished by preheating slowly to 1400°F., and then heating rapidly to full forging temperature. U S S 17 works much like low carbon steel except that it is stiffer at all temperatures.

2. **Annealing**—Annealing has a somewhat special meaning in the case of U S S 17. Hot working leaves the metal in a condition somewhat resembling a very low carbon martensite and, as this is not compatible with full ductility, the restoration is provided by an annealing treatment, which accomplishes removal of the worked or distorted structure and serves to coalesce the few carbide particles into a spheroidal form. The material is not hardenable by heat treatment.

Generally speaking, annealing is accomplished by heating to about 1400°F.

The metal may be cooled as rapidly as is desired; in any event the effects of either hot or cold work are thus removed and a ductile metal is provided for further working. The fine-grained structure secured by a low-temperature anneal after a little cold work is associated with the highest ductility.

3. Welding—U S S 17 can be welded by the electric resistance, electric arc, or oxy-acetylene torch methods. A welding rod of the same material or of U S S 18-8 is used, and in the case of gas welding a practically neutral flame must be employed.

While U S S 17 welds quite readily, it is subject to grain growth when heated to the welding temperature and, consequently, a condition arises at the welds which cannot be eliminated by heat treatment. The coarse-grained welds are not as ductile as the metal which has not been affected by the operation. Various devices for producing joints are in vogue, and inquiries to the Subsidiary Companies are suggested when welding is contemplated.

Hammer welding is not possible with U S S 17.

4. Forming and Deep Drawing—Deep drawing operations on U S S 17 require more power, more clearance, and more carefully selected lubricants than are required for working ordinary steel. On account of the increased resistance to deformation displayed by this metal, a reduction in the speed of mechanical operations is advisable. The dies must be strong and rigid, and maintained very smooth and well polished. U S S 17 will not withstand some of the very severe deformations for which U S S 18-8 is eminently adapted. However, it will work very much more easily if warmed somewhat—say to 200 to 300°F.

When the draw is too severe for one operation, full ductility can be restored, if necessary, by heating the metal to 1400°F. During the anneal the metal may be contaminated (particularly carburized) if the lubricant is not carefully removed before heating. The choice of a lubricant will depend somewhat upon the ease of removal. The so-called water-soluble lubricants have given satisfactory results in many operations, and the lard oil or linseed oil-sulphur lubricants have been adapted to others. Annealing for further working must be followed by pickling.

5. Riveting—Small rivets, up to ⅝-inch, may be driven cold. In the case of large rivets, heating may be necessary, and care should be taken to keep the temperature relatively low (approximately 1400°F.) and the time of heating as short as possible. Rivets should not be heated in a direct flame. Large rivets should be designed with a fillet under the head and should be driven in countersunk holes.

6. Spinning—U S S 17 may be spun by the methods employed for ordinary steel. Slow speeds and tools of large radius are helpful, and the metal should be in the annealed condition. The annealing practice recommended for forming operations can be used to restore the ductility after spinning operations.

7. Pickling—A hot pickling solution is required for U S S 17. The tempera-

ture should be approximately 150°F. Either hydrochloric (muriatic) acid or its equivalent, sulphuric acid and common coarse salt, is used.

It is customary to employ a solution made by mixing equal parts of commercial hydrochloric acid and water. A bright finish is secured by the addition of a small amount of nitric acid, e.g., 10 to 25% of the volume of the hydrochloric acid.

Where sulphuric acid and rock salt are used, a solution containing 10% sulphuric acid and 10% salt, used at approximately 180°F., is satisfactory.

In all pickling operations the pickling acid should be rinsed off in hot water, and the work then be given a few minutes in hot 10 to 20% nitric acid (about 125 to 140°F.) followed by a wash in hot water.

The ideal tank for the nitric acid dip solution is one made of U S S 18-8, or one lined with this metal.

8. Passivation of Finished Articles—The treatment described for U S S 18-8 (page 18) applies also to U S S 17.

9. Operations Involving Cutting—U S S 17 machines very much like medium carbon steel, with only a moderate tendency to drag, such as is evidenced by many of the high chromium steels. The fine-grained condition resulting from a low-temperature annealing treatment on cold worked metal is conducive to the best results. No unusual behavior accompanies any cutting operations but, in general, a very neat fit in punching and shearing is desirable in order to prevent troublesome dragging of the metal.

Flexible in design, attractive in appearance, durable in service, Stainless Tubing is ideal for artistic furniture and other ornamental pieces

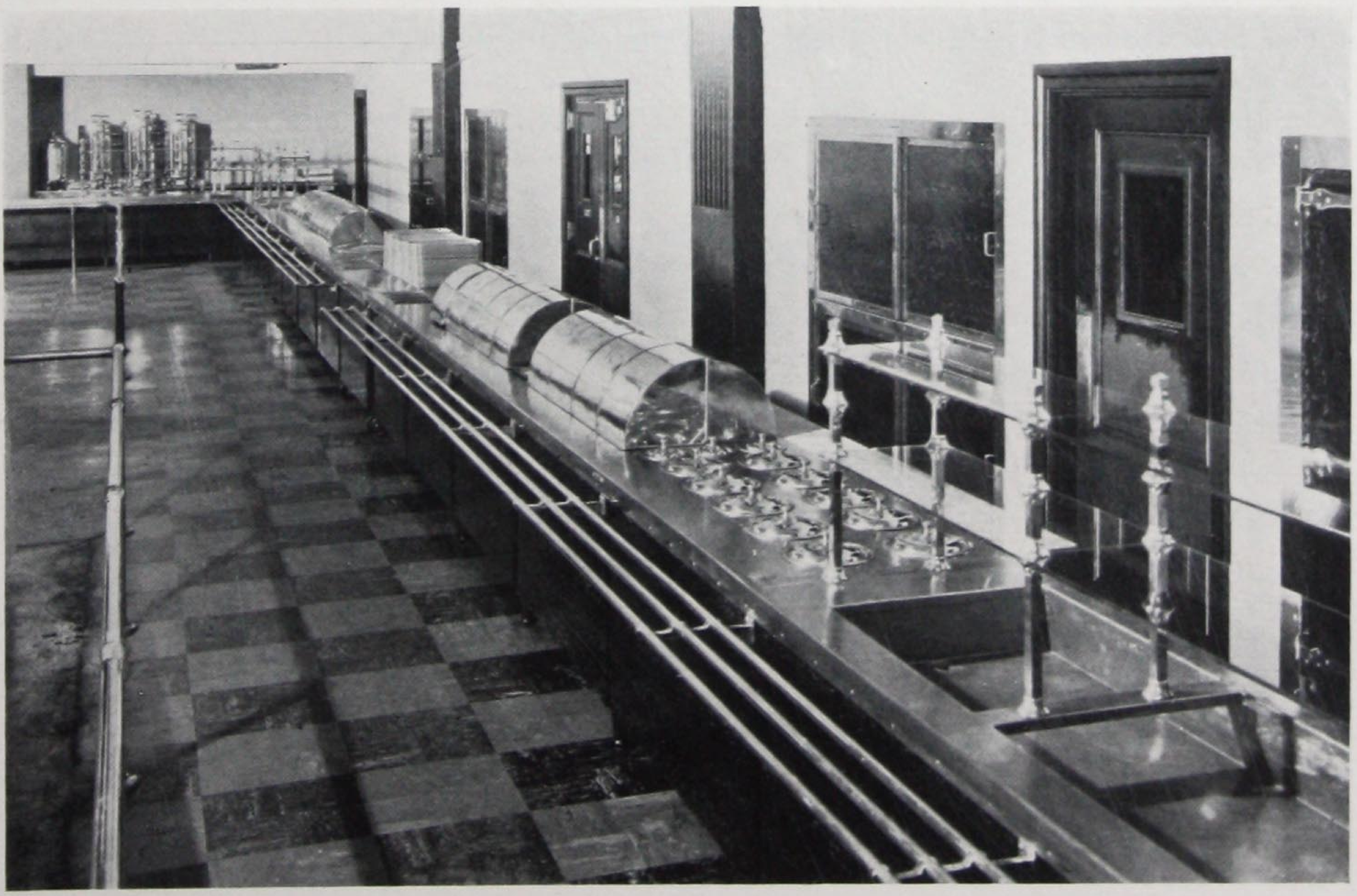
10. Soldering—U S S 17 can be soldered satisfactorily if a sufficiently active soldering fluid is used to remove the protective film which is normally present on the metal surface. For this purpose, the hydrochloric acid-zinc chloride mixture is satisfactory. A little extra time must be allowed in the case of highly polished surfaces. The metal not involved in the joint should be protected from splashes of flux and, finally, the soldered articles must be washed entirely free from traces of the soldering solution. A dilute soda solution is effective for this purpose.

Brazing may be performed on U S S 17, but is not recommended without qualification as there is some uncertainty regarding the metallurgical characteristics of the brazed material. Where some possible impairment of the metal would not be serious, brazing may be employed in the usual manner.

11. Polishing—As with the U S S 18-8 alloy, the methods of polishing U S S 17 vary so greatly with the nature of the articles that it is impossible here to give any detailed instructions. However, the considerations mentioned in connection with U S S 18-8 (page 19) regarding choice of abrasives, grinding speeds, etc., apply also to U S S 17.

Caution

When straight chromium steels of this composition are employed for very long periods of time at temperatures in the vicinity of 900°F., no impairment of the alloy is observed *while the temperature is maintained* but, upon cooling, a loss of ductility may result. To obviate this effect, a rise in temperature to 1400°F., just prior to cooling the metal, will entirely circumvent the trouble.



The smooth, bright, non-tarnishing character of Stainless Tubing makes it useful in cafeterias for tray slides, rails, guards, etc.

Metallurgical Nature of U S S 17

U S S 17 is a solid solution of chromium in alpha iron (ferrite) and, in the main, remains unchanged at all temperatures up to the melting point. This is due to the influence of chromium in suppressing the transformation to austenite. However, at forging temperatures, a small portion of the metal actually transforms to austenite and, upon cooling, these small "pools" transform again to a slightly hard martensite. This circumstance is of significance only in respect to ductility. The annealing process softens these microscopic regions and precipitates the very minute proportion of carbide.

Recrystallization after cold work may begin as low as 1200°F., but higher temperatures bring about the recrystallization more rapidly. As in all metals which, like U S S 17, do not have transformations, grain refinement cannot be brought about by heat treatment alone. The grain size is kept fine by finishing the forging or hot rolling at temperatures below that of grain growth, or by cold working followed by the lowest possible annealing temperature (about 1300°F.).

At elevated temperatures as high as 1550°F. a thin adherent scale is formed which does not crack away, to any extent, upon cooling. This circumstance permits the use of U S S 17 in intermittent heating operations, for the protecting scale does not have to reform with each reheating.

In preparing specimens for microscopic examination, it is necessary to alternately etch and polish on the final cloth several times in order to secure representative structures for observation. Disturbed metal obliterates grain boundaries and carbide particles, unless it is gradually removed by this method. The metal is disturbed by the early abrasives rather more deeply than is the case with other metals.

U S S 21

As will be evident from the earlier discussions of U S S 18-8S and U S S 18-12, both the austenitic and the ferritic stainless alloy compositions are subject to modification to adapt them to particular uses. U S S 21 is an example of such adaptation. It is a ferritic steel containing considerably more chromium than U S S 17, and is superior to that alloy in corrosion and heat resisting properties. In general, increasing the chromium content increases the general corrosion resistance as well as the resistance to oxidation at elevated temperatures. The analysis, as well as the cost, of U S S 21 is intermediate between those of the alloys U S S 17 and U S S 27. These facts justify the existence of U S S 21, both technically and economically.

USS 12

U S S 12 IS SIMILAR to the early high chromium, low carbon steels and is still one of the few materials selected for certain applications wherein high physical properties are necessary and corrosion resisting requirements are not the most exacting. Both physical properties and resistance to corrosion are fully developed only by a final heat treatment. U S S 12 is sometimes described as a low carbon modification of the cutlery type of stainless steel, with attendant toughness and the particular sort of corrosion resistance exhibited by the high chromium alloys, which are hardenable somewhat after the manner of the tool steels. It is distinguished by being the only one of the U S S series which is normally strengthened by a conventional hardening operation consisting of an oil or air quench from a suitably high temperature.

Typical uses for U S S 12 are in turbine blades, coal screens, pump rods, golf clubs, parts of mine pumps, valve stems and seats, bolts and nuts, etc.

Composition

When the carbon content is relatively low, or the chromium content relatively high, the response to heat treatment, as a strengthening or hardening operation, is diminished; but from the standpoint of corrosion resistance the need for the heat treatment is likewise diminished. The composition is therefore subject to modification, depending upon the mechanical requirements of the proposed application, but will usually fall within the limits set forth below:

Chromium	12 to 14%	Silicon	Max. 0.50%
Manganese	Max. 0.50%	Carbon	Max. 0.10%

Note: U S S 12z is a special modification of U S S 12, with its composition and processing adjusted to provide unusual ease of machining. It may be handled in automatic machine tools without reduction of speeds.

Physical Properties

In U S S 12 high physical properties may be developed by heat treatment, and its value in service depends largely upon its superior strength. However, as the fabrication of this steel is best performed with annealed material, some of its properties are listed in the table on page 47. They are not unlike those of a mild steel, but by a simple heat treatment, which also develops the full resistance to corrosion, U S S 12 acquires an outstanding combination of strength and toughness. Properties developed by quenching in oil from 1700 to 1750°F. and tempering at 1100°F. are also given in the table.

The physical properties of U S S 12 depend so largely upon precise composition and time of tempering that only approximate figures can be listed. Some of the values enumerated may be exceeded by suitable treatment, described subsequently.

Resistance to Corrosion

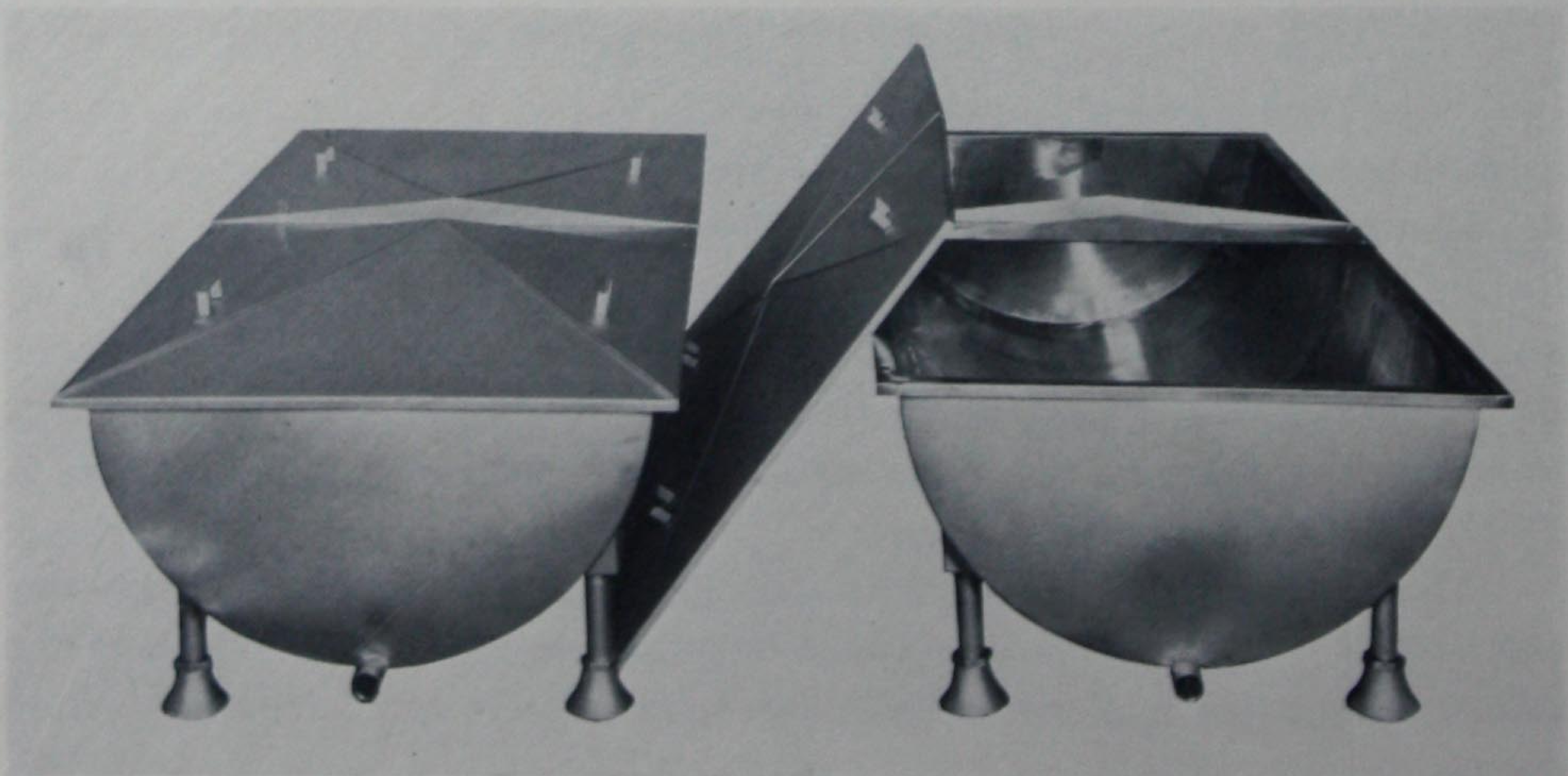
When the chromium content of U S S 12 is on the high side of the usual range and the carbon content is at the lowest, this alloy, even as annealed or rolled, resists ordinary atmospheric corrosion; but with the composition changed to other proportions, heat treatment is required for the development of its full inertness. When so treated it resists attack in the same general class of environments as does U S S 17. Obviously, wherever heat treatment is undesirable, and the characteristic strength and toughness of U S S 12 are not demanded, the use of U S S 17 is preferred.

In any event, the surface of U S S 12 exposed to potential corrosion should be ground or polished for the removal of foreign particles, if it is to remain free from stain and attack. This alloy steel takes a particularly fine polish, having a platinum-like lustre. Its resistance to oxidation at high temperature is well pronounced, only a thin film evidencing any oxidizing attack up to the range wherein excessive tempering would result from the temperature used.

Recommended Procedures for Use of USS 12

1. **Forging**—Heat about twice as long as for ordinary steel. A preheat at 1450°F., with a subsequent, and more rapid, heating to 2100°F. prepares the metal for forging. It may be forged without injury until the temperature has dropped to 1450°F., but effective deformation is rather difficult below 1650°F. Reheating is recommended at this point. In order that the forged metal may be machined readily without a special annealing, it must be cooled very slowly from the forging heat.

2. **Annealing**—For complete softening, the normally cooled or cold worked metal is preferably heated for some time at 1300 to 1400°F. Good machining properties are thus developed.



Vats of Stainless Steel. One of the many applications of Stainless in processing of dairy products

3. **Welding and Soldering**—U S S 12 may be welded either with the oxy-acetylene torch or with the electric arc, but cannot be hammer welded. Welding rods of U S S 17 are best suited for this purpose; coated rods for use in the electric arc and uncoated rods for gas welding. If the carbon content of the metal is not on the low side, welding may cause air hardening and a zone of somewhat lowered corrosion resistance at a distance from the weld. Wherever possible, welded metal should be annealed in accordance with the recommended practice. Hard soldering is quite satisfactorily applied to U S S 12 and, in general, is preferred to welding as the less extensive rise in temperature need not cause any serious change in properties.

4. **Machining**—Most of the high chromium alloys show a tendency to drag when machined, but annealed U S S 12 works very well without special provisions. U S S 12z compares favorably with the best high sulphur screw stock in machinability, except that slightly more power is required.

5. **Pickling**—U S S 12 can be pickled in a solution of hydrochloric (muriatic) acid in the same way as U S S 17, and similarly requires a final dip in nitric acid to develop the permanent silver-gray surface. See the procedure on page 31.

6. **Passivation of Finished Articles**—The treatment described for U S S 18-8 (page 18) applies also to U S S 12.

7. **Polishing**—Proceed as in the case of U S S 18-8, and avoid the use of compounds containing iron oxide.

The Strengthening Treatment

Notwithstanding the low carbon content of U S S 12, it is amenable to the process of hardening common to all ordinary steels, except that it does not develop the great hardness and brittleness of tool steels. The best temperature for this treatment is about 1700 to 1750°F., followed by a rapid air cool for thin sections and an oil quench for larger sections. Certain articles, such as springs, are used in this condition. Usually, however, some of the strength resulting from this treatment is sacrificed, by tempering at a temperature below 1100°F., in order to secure a very great gain in toughness. When tempered at 1100°F., the Brinell hardness is about 230. It is customary to select the minimum tempering time and temperature required to secure the needed toughness or ductility. Adequate impact strength, e.g., 75 ft-lb., can be secured by a tempering practice which still does not reduce the corrosion resistance. In connection with the heat treatment, the precise composition plays an important part. The most satisfactory method of suiting the metal to the application is to make inquiry of the producer, indicating the nature of the intended use and the general trend of properties demanded. Then the composition will support the heat treatment to assure the best combination of physical characteristics.

For beautiful and unusual effects, U S S Stainless Steel is matchless material in doors, trim, plaques and other decorative applications

U S S 27

U S S 27 IS USED principally for service at temperatures between 1500 and 2100°F. It has been successfully used for furnace linings and other furnace parts, air and gas preheaters, annealing boxes, exhaust manifold valves, and other similar applications. U S S 27 may be obtained in the form of sheets, plates, rounds, flats, bars, and seamless tubing.

Composition and Properties

The usual composition of U S S 27 is as follows:

Chromium	25 to 30%	Silicon	Max. 0.50%
Manganese	Max. 0.50%	Carbon	Max. 0.10%

In common with U S S 12 and U S S 17, U S S 27 is ferritic throughout the temperature range and is magnetic.

Typical physical properties of U S S 27 are listed in the table on page 47.

U S S 27 becomes hard or stiff when subjected to cold work, but the strains may be relieved by proper annealing. This alloy steel cannot be hardened by heat treatment. Prolonged heating at high temperatures favors the development of a large or coarse grain structure which reduces the toughness of the metal when cold.

Notwithstanding the indications of fair ductility, as expressed by the results of tensile tests, U S S 27 does not lend itself, in the cold, to fabrication requiring severe forming or drawing. However, some operations not feasible with this alloy

Made of gleaming U S S Stainless Steel, this beautiful soda fountain on a recently built American liner is in perfect harmony with the other modern decorative features

at room temperatures, can be performed satisfactorily if the metal is heated to 300 to 500°F.

Because of the high chromium content of U S S 27, it shows pronounced resistance to corrosion. However, in general, it will be found that, aside from service at high temperatures (1500 to 2100°F.), other alloys of the U S S series are to be preferred from the standpoint of better workability. U S S 27 is being successfully used to withstand both oxidizing and reducing gases at temperatures up to 2100°F. Even at these high temperatures, it shows remarkable resistance to the action of sulphur-bearing gases.

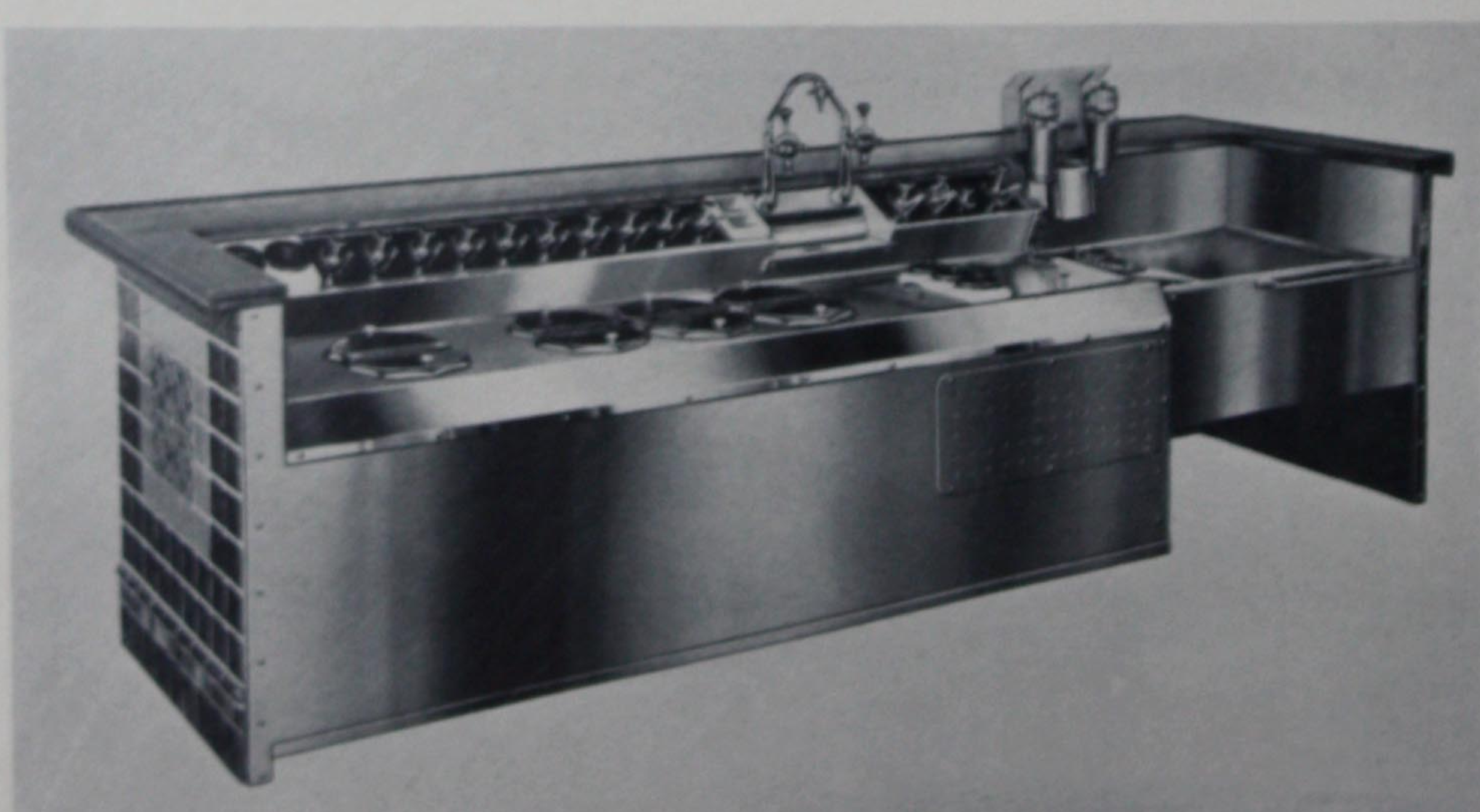
Recommended Procedures for Use of U S S 27

1. **Forging**—In heating U S S 27 for forging, it should be soaked at 1300 to 1400°F. and then heated rapidly to 2200°F. Because of its low thermal conductivity, this material requires what might seem an excessively long time to reach the required temperature, especially in the case of heavy sections. Experience will soon indicate the best procedure.

The first blows in forging should be relatively light, and the working should be continued until the temperature of the piece has fallen below 1500°F. This operation should be followed by annealing.

2. **Annealing**—The recommended procedure for annealing U S S 27 is to soak the alloy for one hour or longer (depending on the cross section) at 1450°F. and then cool rapidly.

3. **Welding**—U S S 27 may be satisfactorily welded by resistance methods, the metallic arc, or the oxy-acetylene torch. It cannot be hammer welded. Filler rods of the same composition, or of U S S 25-12, should be used. The procedure



The beautifully polished and non-tarnishing surface of Stainless Steel lends an inviting and refreshing air to beverage-dispensing equipment

given on page 13 for welding U S S 18-8 is applicable. The limitations suggested for U S S 17 apply also to U S S 27.

4. Pickling—Since U S S 27 is used almost exclusively for apparatus subjected to high temperatures, it is seldom found necessary to pickle the alloy. However, it may be pickled by the procedure given for pickling U S S 18-8 or U S S 17.

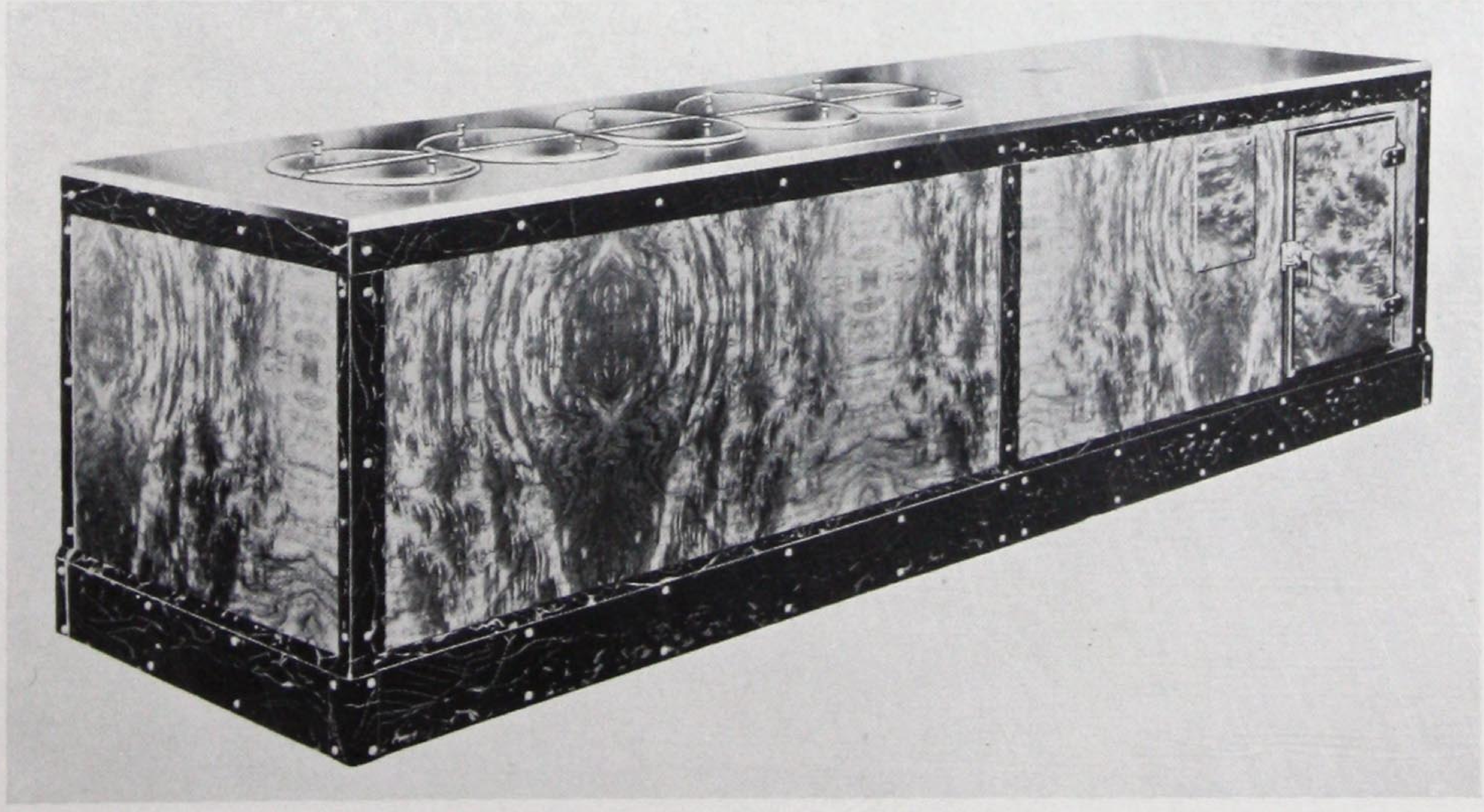
Caution

If U S S 27 is maintained at temperatures in the vicinity of 900°F., or is cooled slowly through this range, it will develop a characteristic loss of ductility much in the manner described under U S S 17. It should be remembered that the loss of ductility is manifest not *at* 900°F. but upon subsequent cooling to room temperature. To obviate this, the metal should be reheated to 1200 to 1400°F. and quenched or cooled rapidly.

Discussion

In the choice of an alloy steel for use at relatively high temperatures there is often a question as to whether U S S 27 or U S S 25-12, which is described in a later section, is the more suitable. An inflexible distinction should not be drawn between these two alloy steels, as the choice may depend upon the peculiar factors involved in each case under consideration. Prospective users are invited to discuss their requirements with representatives of the producing Companies.

On page 43 of this publication a few general principles have been mentioned for the guidance of engineers and manufacturers who have problems in the adaptation of alloy steels to high temperature requirements.



Counter-type freezer cabinet with beautifully polished top of Stainless Steel

U S S 25-12

U S S 25-12, WHILE HIGHLY resistant to a wide variety of corrosive agents, is intended primarily for use at high temperatures. It does not oxidize rapidly below 2100°F. and, in addition, retains a large proportion of its strength and toughness throughout its range of application.

U S S 25-12 is obtainable in plates, sheets, rods, flats, and bars, but is usually not produced in the form of seamless tubing.

Composition and Properties

The usual range of composition of U S S 25-12, with respect to the more important constituents, is given in the following table:

Chromium	22 to 28%	Carbon	Max. 0.25%
Nickel	12 to 16%		

The other usual elements in the alloy are regulated in accordance with the conditions to be encountered in service.

As may be inferred from a knowledge of its composition, U S S 25-12 is normally an austenitic alloy, non-magnetic, and in common with other members of its series, cannot be hardened appreciably by heat treatment. The values given in the table on page 47 represent some of the significant properties of the material in the annealed condition.

U S S 25-12 finds its most frequent and logical application where a strong, tough alloy is required for service at temperatures between 1500 and 2100°F., and in certain specific cases involving severely corrosive conditions. Even when an appreciable amount of sulphur is present in the surrounding gases, this metal resists deterioration in a noteworthy manner.

From the standpoint of ease of fabrication at ordinary room temperatures, the ductility of U S S 25-12 is sufficient to provide for a considerable amount of drawing and forming.

Recommended Procedures for Use of USS 25-12

1. **Forging**—In forging U S S 25-12, heat the blank to 2200 to 2300°F. and work until the temperature has fallen to 1800°F. If further deformation is required, reheat to the forging temperature. On account of its low thermal conductivity—about one-third that of plain carbon steel—considerable time must be allowed for heating this metal. U S S 25-12, even when hot, is rather tough and unyielding and will require more severe blows than does ordinary steel. The forging operation should be followed by annealing.

2. **Annealing**—The procedure recommended for softening U S S 25-12 is to heat the metal to a temperature within the range 1900 to 2150°F., bearing in mind its low thermal conductivity. The time required cannot be specified ac-

curately, as it varies with the cross section of the piece, but a period of five to ten minutes at the annealing temperature is usually sufficient. Rapid cooling (quenching) favors the development of the best physical properties and the maximum corrosion resistance.

3. Welding—Strong, ductile welds are obtainable with U S S 25-12 by resistance methods, the electric arc, or the oxy-acetylene process. Hammer welding is not feasible. Filler rods of U S S 25-12 should be used; coated rods are preferred for arc welding. The procedure outlined for U S S 18-8, page 13, is applicable to U S S 25-12.

4. Pickling—In the rare instances when it is necessary to pickle U S S 25-12, this operation may be accomplished by the procedure given for U S S 18-8, page 18.

Discussion

Both U S S 25-12 and U S S 27 are described as alloy steels for use at high temperatures. For many purposes either one or the other may be used with equally good results, but since there are some considerations which may lead to a choice between the two, they will be mentioned briefly:

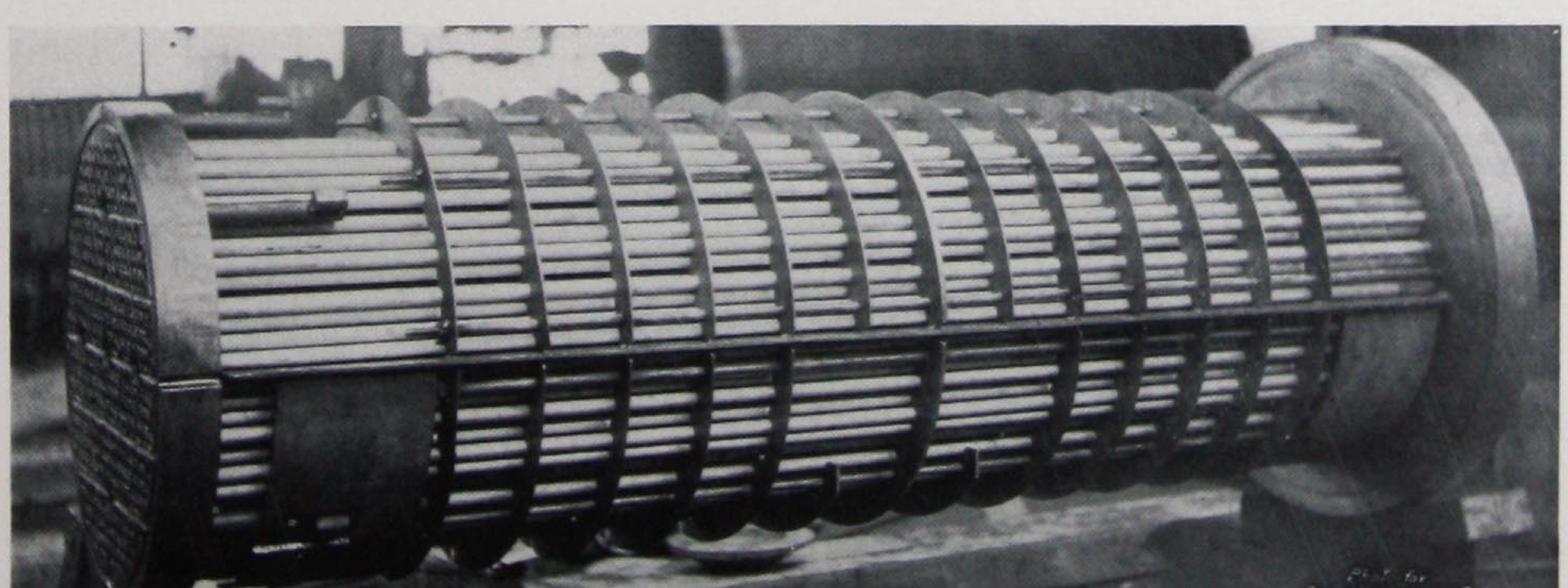
1. The cost of U S S 27 is usually less than that of U S S 25-12.

2. From the standpoint of ductility at ordinary temperatures, U S S 25-12 has some advantage over U S S 27. It will stand more forming and manipulation.

3. Where strength and resistance to stress after long periods of service at high temperature are particularly important, U S S 25-12 likewise will be found to have some advantage.

4. U S S 27 resists oxidation as well as does U S S 25-12, and for some operations in which alternate heating and cooling are involved it may outlast the chromium-nickel alloy.

5. For facility in welding, and ductility of the welds, the austenitic alloy (U S S 25-12) is preferable to the ferritic alloy (U S S 27).



Longer service and greater safety are obtained in heat exchangers and similar equipment by the use of Stainless and Heat Resisting Steel Tubes

Battery of Stainless Steel pasteurizers

Sanitary lines of U S S Stainless Tubing—a logical complement to efficient dairy plant equipment

A Few Typical Applications

OF THE CHROMIUM AND CHROMIUM-NICKEL ALLOY STEELS OF THE U S S SERIES

Airplanes—Structural Members, Exhaust Pipes

Annealing Operations—Annealing Boxes, Pots, Bottoms; Parts of Furnaces, Carrier Sheets for Normalizing Furnaces

Architectural and Building Purposes—Interior and Exterior Trim, Door Plates, Panels, Moldings, Bank Vaults, Decorative Grilles, Railings

Automobiles—Radiator Shells, Lamps, Hub Caps, Spokes of Wheels, Cowl and Running Board Molding, Door Handles, Hinges, Bumpers, Pump Shafts, Miscellaneous Trim

Bakery Equipment—Dough Mixers, Troughs, Baking Pans

Cafeteria and Hotel Equipment — Utensils, Trays, Sinks, Shelving, Dish Washers, Table Tops, Counters, Steam Tables

Carburizing Boxes and Crates

Chemical Plant Equipment — Structural Supports, Apparatus, Piping

Cooking Utensils for Domestic Purposes

Dairy Equipment—Pasteurizers, Coolers, Milk Pails, Cans, Tanks, Sanitary Lines

Electric Household Appliances

Fans

Furnace Construction

Furniture

Gas Stoves, Mantels, Parts of Burners

Jewelry—Cigarette Cases, Compacts, Watch Cases, Novelties

Kettles, Steam Cookers

Laboratory Apparatus, Ovens, Tongs

Paper Industry—Blow Pit Bottoms, Relief Gas Lines and Coolers, Acid Circulation Systems, Digester Linings

Petroleum Refining — Bubble Caps, Linings for Various Apparatus, Still Tubes, Heat Exchangers, Ducts

Plumbing Accessories—Sinks, Troughs, Trim

Preheaters — Regenerative and Recuperative Heaters for Furnaces, Stills

Pump Rods and Liners

Refrigerator Hardware and Trim

Shipping Containers — for Chemicals, Milk, Beer

Sieves and Screens

Soda Fountain Equipment

Structural Members and Supports

Tableware

Tanks

Tank Cars

Traffic Markers

Trunk Corners and Trim

Turbine Blades

NOMINAL PROPERTIES OF U S S

MATERIAL IN THE ANNEALED CONDITION UNLESS OTHERWISE NOTED

ITEM No.	Physical Properties	U S S 18-8	U S S STABILIZED 18-8
	Specific Gravity		
1	lb./cu. in.	0.286	0.285
2	low carbon steel = 1.00	1.01	1.01
	Specific Electrical Resistance		
3	microhms/cm.^{3}	70 (cold worked = 70–82)	71
4	microhms/in.^{3}	27.6 (cold worked = 27.6–32.3)	28
5	low carbon steel = 1.00	6.4	6.5
6	Melting Range, °F.	2550–2590	2550–2590
7	Structure	Austenitic	Austenitic
	Magnetic Permeability		
8	as annealed	$\mu = 1.003$	$\mu = 1.003$
9	after 10% reduction of area	$\mu = 1.10$	....
	Specific Heat		
10	cal./°C./gm. (0 to 100°C.)	0.12	0.12
11	B.t.u./°F./lb. (32 to 212°F.)	0.12	0.12
12	low carbon steel = 1.00 (0 to 100°C.)	1.1	1.1
	Thermal Conductivity		
13	cal./cm.^{2}/sec./°C./cm., at 100°C.	0.0390	0.0385
14	B.t.u./sq. ft./hr./°F./in., at 212°F.	113	112
15	low carbon steel = 1.00, at 100°C.	0.33	0.32
16	cal./cm.^{2}/sec./°C./cm., at 500°C.	0.0515	0.0528
17	B.t.u./sq. ft./hr./°F./in., at 932°F.	150	153
	Coefficient of Thermal Expansion		
18	per °F. $\times 10^{-6}$ (32 to 212°F.)	9.6	9.3
19	low carbon steel = 1.00 (32 to 212°F.)	1.45	1.40
20	per °F. $\times 10^{-6}$ (32 to 932°F.)	10.2	10.3

ITEM No.	Mechanical Properties at Room Temperature	Annealed	Cold Worked (Wire)	Stabilized
21	Tensile Strength, 10^3 lb./sq. in.	80–95	105–300	80–95
22	Yield Point, 10^3 lb./sq. in.	35–45	60–250	35–45
23	Modulus of Elasticity, 10^6 lb./sq. in.	29	.....	....
24	Elongation in 2 in., %	55–60	50–2 (10″)	50–55
25	Reduction of Area, %	55–65	65–30	55–65
26	Charpy Impact Strength, ft-lb.	.....	.....	77
27	Izod Impact Strength, ft-lb.	75–110	.....	....
28	Endurance Limit (Fatigue), 10^3 lb./sq. in.	47	.....	....
29	Brinell Hardness Number	135–185	170–460	135–185
30	Rockwell Hardness Number	B75–90	C5–47	B75–90
31	Erichsen Value, mm.	11–14	.....	....
	Stress Causing 1% Elongation (Creep) in 10,000 Hours			
32	At 1000°F., lb./sq. in.	17000		
33	At 1200°F., lb./sq. in.	7000		
34	At 1350°F., lb./sq. in.	3000		
35	At 1500°F., lb./sq. in.	850		
36	Scaling Temperature, °F. (approximate)	1650		1650
37	Initial Forging Temperature, °F.	2200		
38	Finishing Temperature, °F.	Not under 1600–1700		
39	Annealing Treatment	Heat to 1900–2000°F. and quench		
40	Precautions	(B)		

(A) Anneal at 1400°F. after a small cold reduction, and quench.
(B) Preheat slowly to 1600°F., then heat rapidly to the forging or annealing temperature. Exposure to temperatures between 1000 and 1500°F. produces marked susceptibility to intergranular corrosion. If the metal is unattacked, this can be cured by repeating the annealing treatment.

STAINLESS and HEAT RESISTING STEELS

DATA COMPILED BY U. S. STEEL CORPORATION RESEARCH LABORATORY, APRIL 1933

U S S 18-12	U S S 25-12	U S S 12	U S S 17	U S S 27	ITEM No.
0.287	0.283	0.276	0.273	0.270	1
1.02	1.0	0.97	0.96	0.95	2
73	78	57	59	67	3
28.7	30.7	22.4	23.2	26.4	4
6.7	7.1	5.2	5.4	6.1	5
.....	2530–2570	2750–2790	2710–2750	2710–2750	6
Austenitic	Austenitic	Ferritic	Ferritic	Ferritic	7
$\mu=1.003$	$\mu=1.003$	Ferromagnetic	Ferromagnetic	Ferromagnetic	8
$\mu=1.006$	$\mu=1.003$	Ferromagnetic	Ferromagnetic	Ferromagnetic	9
0.12	0.12	0.11	0.11	0.11	10
0.12	0.12	0.11	0.11	0.11	11
1.1	1.1	1.0	1.0	1.0	12
0.0380	0.03–0.04	0.0595	0.0583	0.0500	13
110	87–116	173	169	145	14
0.32	0.25–0.34	0.50	0.49	0.42	15
0.0520	....	0.0686	0.0624	0.0583	16
151	....	199	181	169	17
9.9	8.3	6.1	6.0	5.9	18
1.50	1.26	0.93	0.91	0.90	19
10.8	9.6	....	6.7	6.3	20

Annealed	Cold Worked (Wire)	Annealed	Cold Worked (Wire)	Annealed	Quenched and Drawn at 1100°F.	Annealed	Cold Worked (Wire)	Annealed	Cold Worked (Wire)	ITEM No.
80–90	105–275	90–110	110–270	65	125	75	100–190	75–95	85–175	21
40	....	40–60	65–230	35	100	40	....	50–60	55–155	22
..	....	..	....	28	....	29	....	....	....	23
60	50–2 (10″)	35–50	35–2 (10″)	35	20	27	25–2 (10″)	20–30	25–2 (10″)	24
65	65–30	45–60	55–20	65	60	55	40–20	50–60	55–25	25
....	....	....	....	....	75	....	....	....	....	26
....	....	....	....	80	....	8–25	....	....	....	27
....	....	....	....	....	....	....	....	....	....	28
135–165	170–380	150–185	170–375	140	230	175	185–270	160–190	150–250	29
B75–85	C5–40	B80–90	C5–40	B76	C22	B85	B90–105	B80–90	C0–25	30
....	....	....	....	....	....	7–9	....	....	....	31

U S S 18-12	U S S 25-12	U S S 12	U S S 17	U S S 27	ITEM No.
		13000	8500	....	32
		2300	2100	1600	33
		1400	1200	400	34
		....	....	....	35
1650	2100	1300	1550	2100	36
2200	2200–2300	2100	2000	2200	37
Not under 1600–1700	Not under 1600–1700	Not over 1450	Not over 1400	Not over 1400–1450	38
Heat to 1900–2000°F. and Quench	Heat to 2000–2150°F. and Quench	Prolonged Heating at 1250–1350°F.	(A)	Heat one hour or more at 1450°F. and Quench	39
(B)	(B)	(C)	(D)	(D)	40

(C) Preheat slowly to 1450°F., then heat rapidly to 2100°F. for forging. Full corrosion resistance is developed only in the heat treated condition. (Temper below 1000°F.)

(D) In forging, preheat slowly to 1450°F. Excessive grain growth takes place above 2000°F. Expert welding is required to avoid excessive grain growth. Prolonged exposure at 850 to 950°F. produces cold brittleness. To prevent this, heat to 1400°F. before cooling, and quench.

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